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Proceedings

of the

Second Annual Meeting

of the

WESTERN CANADIAN SOCIETY OF AGRONOMY

Held in Winnipeg
Dec. 27, 28, 29, 1921

PRICE: FIFTY CENTS

PUBLISHED BY
MANITOBA DEPARTMENT OF AGRICULTURE
AND IMMIGRATION
WINNIPEG, MANITOBA

CONTENTS

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Western Canadian Society of Agronomy

MEMBERSHIP

Membership shall consist of persons who are engaged in teaching or in scientific investigation in some branch of Agronomy, and other persons interested in the objects of the Society. Membership may be secured by the endorsement in writing of two members and upon approval of the Executive Committee and the payment of annual dues.

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Plant Pathology—Chairman, Miss M. Newton
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RESOLUTIONS

Moved by Prof. Champlin, seconded by Dr. Bedford, that the following resolutions be adopted and that the Secretary inform the parties concerned by personal letter:

1. We wish to express our hearty appreciation for the excellent entertainment and the many courtesies shown us by the Manitoba Agricultural College and the Manitoba Department of Agriculture.

2. We also wish to thank the officials of the Dominion Seed Branch, the Dominion Grain Inspection Branch, Winnipeg Grain Exchange and others who have given us assistance in insuring the complete success of our meeting in Winnipeg.

3. We further wish to thank those who have so kindly assisted in our program, including Dr. Alway, Prof. Hayes, Dr. Magill and Mr. Jackson, and to assure them that their services are highly valued by our organization.

4. We respectfully recommend to the consideration of the Dominion Government and the three provincial Governments that the more liberal use of funds for publication of information and results of experiments would be desirable.

5. Since the determination of our agricultural resources, more particularly those that are potential in the soil, is of vital importance to the development of the prairie provinces, we wish heartily to commend the several governments of these provinces for the start that has been made in soil survey work in each province and to urge that this work be prosecuted with increasing force until completed.

6. That this Society urge upon the Minister of Agriculture for Canada that in modifying the Seed Control Act, Russian Thistle be continued as a noxious weed.

Members

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Mr. W. H. Wright, Dominion Seed Branch, Calgary
Prof. F. A. Wyatt, University of Alberta, Edmonton

Charter Members of Western Canadian Society of Agronomy at Organization Meeting, Saskatoon, Christmas Week, 1919.

President's Address

By T. J. HARRISON

Field Husbandry Department, Manitoba Agricultural College

The purpose of agronomists is to increase the yield, improve the quality and reduce the cost of producing field crops. The agronomist of Western Canada never had a greater opportunity for service than at present. In Manitoba the agricultural survey shows that the yield per acre of wheat has been gradually decreasing at the rate of one bushel per acre in every ten years. The quality of the crop is not equal to the virgin soil product of earlier years. The cost of production is increasing as the yield and quality decrease. The same condition is to be noted to a greater or less extent with the other grain crops. If this be true of Manitoba, it is also true of the older and drier sections of Saskatchewan and Alberta.

The primary factors responsible for the present conditions of crop growing in Western Canada are the weather, soil, seed, weeds, insects and plant diseases. To overcome the bad effect of these factors, it is necessary that agronomists in all phases of their work increase their energies.

Weather—A study should be made by meteorologists and field husbandmen of the relation of weather to crop production. This would entail investigating the effect of precipitation, temperature, wind velocity, sunshine and hail on crop production in the different areas of the West.

Soil—The soil surveyor, soil chemist, soil physicist and soil bacteriologist have almost a new field in Western Canada. Until the soils are studied and the trouble ascertained, little or no progress can be made in regard to their improvement.

Seed—The field husbandman, plant breeder and seed analyst have done considerable work on crops in Western Canada. Their work in the future will be: First, in determining crops and varieties suitable for the different agricultural areas in each province; second, the development of varieties better suited to the conditions of soil and climate in these areas.

The seed analyst and administrators of the seed laws have a big task in improving the purity and vitality of the seed sown. In this connection the survey has shown that farmers are sowing seed of very low quality, particularly from the standpoint of impurities.

Weeds—It has been estimated that the farmers of Western Canada pay annually sixty million dollars for the privilege of growing weeds. The botanist and field husbandman must at least prevent an increase in this amount. New weeds must be identified and eradicated, and methods of controlling old ones developed.

Insects—New insects are continually making their appearance. The entomologist and field husbandman must determine methods of control if crop production is to remain profitable.

Plant Diseases—The wheat crop alone is subject to twelve or more diseases. The plant pathologist, plant breeder and field crops experimenter have a big problem in overcoming the ravages of the different diseases attacking field crops.

The foregoing, in brief, gives some idea of the problems facing the agronomist in Western Canada at the present moment. The purpose of the Western Canadian Society of Agronomy, and particularly of the present convention, is to determine the best means of attacking these problems. While the society, up to the present, has probably no great achievement to its credit, the statement may be safely made that much has been done to standardize the methods used by the agronomists in various phases of their work. A new departure has been made in the present convention, namely, that of bringing in experts from outside the country. The idea is to have the

latest word on the solution of the various problems. I trust that the deliberations of the members throughout this convention will be frank and harmonious and that we may all go back to our individual work instructed and enthused.

Growing Grain in Rows

By MANLEY CHAMPLIN

Field Husbandry Department, University of Saskatchewan

Need for New Methods

The development of Saskatchewan has been based upon the production of wheat and oats. To conserve moisture and destroy weeds, it has been the custom to summerfallow once in two, three or four years, varying according to local soil and climatic conditions.

This practice has usually proved profitable in the various districts as long as land was cheap and retained enough of its original fiber to prevent it from drifting, providing that the market prices of wheat and other grains were relatively high.

At present certain factors are operating to force a change in this scheme of operating a prairie farm. Just which of these is entitled to be called chief would be difficult to say, but each one exerts its influence towards a change.

In many districts trouble is now experienced with soil drifting. The fallow lands are exposed to weathering for nearly twelve months with the resulting movement of soil. The effects of drifting soil are so evident that it is not necessary here to dwell upon them.

Market values of grain crops are no longer sustained by war inflation, and it is necessary to cast about for methods by which to produce cheaply in order to compete in world markets.

Land values in some districts have advanced to a point where the interest and tax charges against a fallow acre for a year have become a real hardship to carry, often destroying all hope of profit in wheat production, or creating an actual loss to the grower.

Letter after letter and caller after caller coming to the Saskatchewan University Field Husbandry Department make statements which, reduced to their briefest form, can be summed up in the words, "*We must change our method of farming or give up.*" *Most of them are not expecting to give up, but are planning to work in certain adjustments or changes that will tend to insure the farm income and lower the cost of production of the chief market product—wheat.*

Possible Fallow Substitutes

With this introduction, it will be plain to all that any crops that can be used as a substitute for part of the fallow will be welcomed at this point in our agricultural history. Some are trying corn, and others potatoes. These crops serve the purpose for a very limited acreage, but since corn is only dependable as a forage crop and potatoes do not find a ready market in large quantities at profitable prices, it remains for us to find something else that can be grown on a large acreage to replace a material percentage of the present summerfallow.

This leaves us the natural crops to which the province is best adapted—wheat, oats, barley and spring rye. Of these four, oats has certain advantages as a cultivated crop. It is the chief feed grain crop, and is used in large quantities as a hay crop, usually spoken of as "green sheaf feed." Therefore, if cultivation retards ripening or causes uneven maturity, the oats may be cut for sheaf feed without any considerable loss.

To grow grain crops in rows, it is necessary to devise a special method of seeding, but it is not necessary to buy a new seeder. The only new implement required is a corn cultivator, and if one possesses a garden or one-horse cultivator, he can get along with that the first year or two while he is trying the practice on a small acreage.

How the Idea Originated

The idea of growing grain crops in rows and cultivating them originated during the season of 1911, while I was employed as cerealist at the Highmore Experiment Farm in South Dakota. During that year hot winds were so severe and continued over so long a period that all of the ordinary grain crops were destroyed. Our grain-breeding nursery, which was grown in rows 18 inches apart and kept cultivated to keep out the weeds, was the only grain which headed out in that district. Gophers came in from the surrounding prairie in great numbers in search of green feed, and it was with the utmost difficulty that we were able to save any of our grain-breeding nursery from their ravages. From this some idea can be formed of the severity of the drouth and blistering hot winds which accompanied it.

A Russian agricultural commissioner, by the name of Kol, who was then traveling in the United States, visited Highmore Farm one day while we were engaged in cultivating a part of the grain nursery with a wheeled hoe or hand cultivator. When he noticed that the nursery grain was headed out and all the other grain crops were ruined he asked why we didn't plant all of our grain that way. We told him that the cost of labor would absolutely prohibit that. He stated that much grain was grown in his home province by planting in rows far enough apart so that the women could walk between and hoe out the weeds.

We had long realized that in order to grow grain crops successfully in central and western South Dakota it was necessary to sow them on land that had been summerfallowed or which had produced an intertilled crop the year before. Grain sown on corn ground which had been properly cultivated produced somewhat better than grain sown on summerfallow and rarely failed to produce a satisfactory crop, while grains sown repeatedly by the ordinary method on the same land could be depended upon to fail three years out of five. At that time many farmers grew corn as a fallow substitute, but very few grew enough corn to equal or balance their grain crops. This was particularly true in the northern half of the state. Some other fallow substitute seemed necessary. If the Russian method with grain crops could be adapted to machine culture, the problem would be well on toward solution. Single rows far enough apart for horse cultivation did not seem feasible, so we tried double rows and triple rows spaced 36 and 30 inches apart respectively.

South Dakota Experience

All of the ordinary spring sown grain crops were given a trial for from five to seven years. The net result of these trials was that we found that all of the spring grain crops except flax responded nicely to cultivation. Oats and barley were especially good and wheat was satisfactory. Millet, proso and Sudan grass also were tried, and found suitable for this method of culture.

Thus our list of cultivated crops which formerly consisted of potatoes, corn and sorghum and garden stuff, was expanded to include oats, barley, wheat, millet, emmer, proso and Sudan grass.

The effect of the cultivation of the grain or other crop in rows upon the succeeding crop was observed for seven years, and no material difference could be noted, for example, between the wheat on corn ground, or following summerfallow, potatoes or oats grown in rows. Owing to lack of available land and funds for investigation work, it was impossible to lay out a new project in which a direct and absolute comparison of this kind could be made. We were, therefore, obliged to put in the row grain crops in connection with our crop rotation project; and while we had ample opportunity for observation in a fairly accurate way we had little opportunity to make strictly scientific comparisons of resulting yields of wheat or other grains following the various substitutes.

The detailed results of these investigations have never been published by the South Dakota Agricultural Experiment Station except in the case of Sudan grass and barley.* Under the rules of that station, no results of experiments can be obtained for publication until after they have first been printed in an official bulletin. Hence we are unable to quote actual results for wheat, oats, emmer, proso and millet here. The results with barley, however, are quite representative of those obtained with other grain crops. The tests at Highmore covered a period of five years, 1912 to 1917. The average yields were as follows:

	Bushels
Ordinary drills, 6 inches apart	24.4
Drills 12 inches apart	22.5
Double rows—cultivated 36 inches apart	19.6
Triple rows—cultivated 30 inches apart	23.1

The grain was usually plumper and the quality better from the rows than from ordinary seeding, and the stubble of the row grain left the ground in such nice shape that discing and harrowing was sufficient preparation for the following crop, whereas the ordinary stubble had to be plowed. The drill was set to sow at the same rate per acre in each case namely, 1.5 bushels, but this reduced to 0.75 bushels for the 12-inch rows, 0.43 bushels for the double rows 36 inches apart and 0.64 bushels for the triple rows 30 inches apart.

Thus we were saving more than half on seed grain, were preparing the land better for the next crop, were producing a better quality of grain and very nearly the same average yield by seeding in rows. In the seasons when moisture conditions were favorable, the ordinary seeding yielded the best. In the dry seasons, the rows yielded the best.

Sudan grass results are reported for two years, 1915-16, from five methods of seeding as follows in tons per acre:

	Tons
Drill rows 6 inches apart	2.84
Drill rows 12 inches apart	2.63
Drill rows 36 inches apart	2.14
Drill rows 42 inches apart	1.99
Double drill rows 36 inches apart	2.12

The rainfall was sufficient in both years of this test. The drill was set to sow half a bushel (25 lbs.) per acre for the ordinary seeding and was left at the same set for seeding the rows, thus requiring 12.5 lbs. per acre for the 12-inch drills, 4.1 lbs. for the 36-inch drills, 3.6 lbs. for the 42-inch single drills, and 7.2 lbs. for the 42-inch double drills.

The yield and quality of hay was better from the ordinary seeding than from the rows, but the land was left by the row plantings in a condition comparable to fallow. Sudan grass is a good annual forage crop for late spring seeding, and the results given may be taken as quite representative of results abtained from millet and proso.

In the year 1915 we grew Kubanka wheat, which gave the same yield per acre, namely 15 bushels, in triple rows 30 inches apart, as was produced from ordinary seeding on a 50-acre field divided evenly.

Experiments at the University of Saskatchewan

With the experience quoted above to guide us, we determined to conduct experiments at Saskatoon to learn whether the practice of growing grain in rows as a fallow substitute would prove feasible here.

*Champlin and Winright, S. D. Bul. 174—Sorghum for Forage in South Dakota, Pages 635-636. Champlin, Morrison and Martin, S. D. Bul. 183,—Barley Culture in South Dakota, pages 65-67.

Preliminary experiments were instituted in 1921. The plots used were fairly large, 0.4 acre each. Very encouraging results were obtained. Wheat, oats and barley were included in the tests. Each crop was sown in two-row groups 36 inches apart and in three-row groups 30 inches apart. For comparison yields are included for the same varieties sown in the usual way, as first and second crop after summerfallow. The row grains were sown on land that had grown oats the previous year, 1920, and various crops in 1919, not having been fallowed since 1918.

The yields of grain in bushels per acre and straw in pounds per acre were as follows:

Method of Seeding	Grain Bus.	Straw Pounds
Marquis Wheat		
Ordinary on fallow	37.0	3640
Ordinary, on fall plowing	37.0	3260
Double rows, 36 inches apart	18.5	953
Triple rows, 30 inches apart	22.1	1115
Banner Oats		
Ordinary on fallow	83.5	5220
Ordinary on fall plowing	60.0	2720
Double rows, 36 inches apart	59.6	755
Triple rows, 30 inches apart	63.9	953
Hannchen Barley		
Ordinary on fallow	59.2	3220
Ordinary on fall plowing	56.5	2460
Double rows, 36 inches apart	39.2	565
Triple rows, 30 inches apart	49.4	728

Next year (1922) Marquis wheat will be planted over all of this land and a plot of summerfallow adjoining, in order to secure a direct comparison of the effect of the grain crops in rows and summerfallow upon the yield of wheat.

In addition to the experiment above noted, the Animal Husbandry Department sowed oats in rows as a summerfallow pasture crop with quite satisfactory results.

Co-operative Experiments

During 1921 a few members of the Saskatchewan Field Husbandry Association undertook to grow grain in rows and were kind enough to report the results.

Arthur E. Dowling, Luseland, reports a yield of 35 bushels of Marquis in double rows 24 inches apart as compared with 46.8 bushels from ordinary seeding on fallow. He further states that the rows were one week later maturing than the ordinary, and therefore more affected by rust, but he experienced no trouble with lodging. Flax did not respond well to row culture.

W. L. Noyes, of Saskatoon, reports 5.5 bushels of Marquis in cultivated rows from his farm at Tessier. No comparative yields were given. The season was characterized by protracted drouth.

M. R. Kirk, of Asor, grew 30 bushels of Leader oats in rows and 65 bushels per acre on ordinary seeding. He intends to increase his acreage next year and use the oats for sheaf feed.

M. S. Munn, of Mankota, reports 40 bushels of oats from double rows about 36 inches apart as compared with 78 bushels from ordinary seeding. He says: "I think I will sow triple rows and not so heavy. If it makes as good a fallow substitute as corn; it will pay to grow oats this way." He is planning to compare wheat on corn and oat row ground next season.

J. P. Robinson, of Cadillac, grew 25 bushels of Banner oats per acre by seeding in triple rows 42 inches apart. He cultivated them only once. No comparative yields are given.

J. E. Machacek, of Assiniboia, tried seeding oats in double rows 36 inches apart at different dates, May 10th, 15th and 20th. He secured yields of 33, 35 and 30 bushels per acre respectively in spite of hail and rust. No comparative yields are given.

Further Investigation Essential

As will be seen from the foregoing, the preliminary trials with row grain have been encouraging, but further investigation is required to make certain of the chief points which remain doubtful as follows:

1. How will the yield of wheat after grain in rows compare with the yield of wheat on fallow or on corn ground?
2. Will the return from the grain in rows repay one for the extra labor required as an average for several years?
3. Will any difficulties, such as slow maturing, lodging or rusting, be found to be greater in producing grain in rows than in growing by the usual methods?
4. Will the stubble standing through the winter and the roots remaining in the soil in the spring help check soil drifting?
5. Will weeds in the rows give trouble on the average farm?

At the University of Saskatchewan we will undertake a project in 1922 to determine the effect of various fallow substitutes in the production of wheat outlined as follows:

	Inches Apart		Inches Apart
Oats in double rows	36	Corn in single rows	42
Oats in triple rows	30	Potatoes in single rows	42
Barley in double rows	36	Sunflowers in single rows	42
Barley in triple rows	30	Sudan grass in double rows	36
Wheat in double rows	36	Fallow	
Wheat in triple rows	30		

This series will be repeated in duplicate 0.05 acre-plots, except the Sudan grass, and will rotate or alternate with wheat each year. Since results obtained at Saskatoon will not be convincing or conclusive for other districts, it would be well if an experiment like this or very similar to it could be conducted at other experiment farms in the three prairie provinces. We will welcome any co-operation that may be had in giving the whole proposition a thorough trial.

We will also endeavor to secure 100 volunteers among farmers who will try growing oats in rows as a fallow substitute. Thus any unforseen difficulties that may be concealed in the future with reference to this method of culture will be brought out.

In this paper we have endeavored to set forth a fairly complete resume of the past, present and future as related to growing grain in rows as a partial substitute for fallowing.

Practical Crop Rotations for the Prairie Farmers

By M. J. TINLINE

Dominion Experimental Station, Scott, Sask.

The Need for Rotations

The crop rotation problem is one of the biggest, most far-reaching and vital of all the problems confronting the farmers in Western Canada today. Because of the one-crop system, farmers as a class are financially embarrassed. Soil fertility has been more rapidly depleted than has been necessary. Because grain farming has been followed almost exclusively, the elevator companies at the head of the lakes are at their wits' ends to know how to dispose of the weed seeds, and the vastness of the quantities of weed seeds gives us some idea of the amount of fertility that has been taken out of the land by weed plants required to produce these seeds. Experimental work shows that the soil fibre has rapidly decreased, and soil drifting is further evidence of this destruction. Frequent summerfallowing and injudicious soil tillage annually waste vast quantities of plant food. Good crop rotations properly operated would not only make agriculture in the West more permanent but would insure some yearly returns to the operators regardless of seasonal conditions.

Crops That Are Likely to be Included in Rotations

Grain Crops	Hay and Pasture Crops	Summerfallow Substitutes
Wheat	Western Rye Grass	Corn
Oats	Brome Grass	Sunflowers
Barley	Sweet Clover	Field Roots
Spring and Fall Rye	Alfalfa	Potatoes
Flax	Spring Grain	
Peas	Fall Rye	
	Millets	
	Rape	

How Rotations Increase Profits

The question will naturally arise: Will rotations prove profitable? Turning to the experimental farms' reports, I find that a five-year average at Brandon shows a mixed farming rotation to give 158 per cent more profit than the straight grain-growing rotation of three crops of grain and then summerfallow. The ten-year average from Scott shows a rotation in which grass has been included to give 27 per cent more profit than the grain-growing rotation consisting of two crops of grain and then summerfallow. At the Lacombe Station a mixed farming rotation has given 34 per cent more profit than a straight grain-growing rotation. This is brought about by increased yields from wheat grown on sod land that has been broken up. A comparison of results secured at Scott from wheat grown after breaking up Western Rye Grass sod with wheat grown after ordinary summerfallow for an eight-year period shows an average of 3.25 bushels per acre in favor of growing the wheat on sod land. This is the average increase from three fields each year.

While hay and pasture crops, particularly in the drier districts, do not usually show very profitable returns and summerfallow substitutes may not bring in much revenue, we have to take into consideration the fact that summerfallows are not so frequent as in a straight grain-growing rotation.

Another side to the profit-bearing returns from crop rotations is shown when manure is applied to the land. The average results at Scott from a six-year period where twelve tons of rotted manure was plowed under shows an increased wheat yield of 5

bushels and 42 pounds per acre. Where oats were grown the increase was 12 bushels and 2 pounds and for barley 9 bushels and 41 pounds. This was in the first crop after the manure was applied. To prove that the total returns from the manure are not realized in one year, I would submit the following: Three plots manured in 1915 and again in 1918 were summerfallowed in 1920 and cropped to wheat in 1921. There was an average increase from these three plots of approximately 8 bushels of wheat per acre over their neighboring check plots that had received identical treatment from the time they were broken excepting that they had had no manure.

The adoption of rotations on the farms will distribute the labour more evenly throughout the summer and provide winter employment.

In addition, by-products on the farm that are now wasted or disposed of at low prices, such as straw and screenings and cheap grain, will be fed to live stock and made to bring profitable returns.

Difficulties in the Way of Introducing Rotations

Most of the farms in the West are too large to permit an intensive system of rotations. Variety of soil and climatic conditions and varying types of farms and farmers will necessitate many modifications in any rotations that can be suggested. Then, too, there is the period between the time the farmer adopts a rotation and the time when it brings in a profit, when the farm may not produce as much revenue as it did previously. That is to say, the effects of the rotation may not be felt for a few years after being adopted. The introduction of forage crops can only keep pace with the introduction of live stock. Because of dry climatic conditions, grass pastures do not produce abundantly and dry up early in the season. This makes it necessary to have extensive systems of fencing to provide sufficient pasture. Another difficulty is that the change in the system of farming may necessitate, in many instances, further expenditures for buildings and machinery as well as for fences.

How Crop Rotations Will Be Introduced

There is no doubt that crop rotations will eventually be introduced. It is the only system that will permit agriculture to endure on the prairies. There will no doubt be some instances where the farmer will be in a position to definitely adopt some rotation and have it in operation in two years' time, but for the most part the change will be gradual. Some will start out seeding down part of their farms to produce hay for horse feed, and some will seed down part of their land with a view to more thoroughly tilling the remainder. Summerfallow substitutes will be grown in some cases to provide feed for live stock. At first these may be grown on land that had previously been summerfallowed, and as the farmers become more familiar with handling these crops they will gradually utilize them as cleaning crops.

Plans of Rotations

For the present at least, it would appear to be advisable in suggesting rotations to plan to have about one-half of the cultivated land in grain crops. The next question to be considered is when to seed down; this has always been an uncertain and unsettled question. The following data was secured on the Scott Station, and the figures quoted are the averages for a period of eight years:

	With Wheat Yield of Cured Hay per Acre (lbs.)	Grass Sown Alone Yield of Cured Hay per Acre (lbs.)
Seeded down on summerfallow	2,605	3,959
Sown after roots (turnips)	1,980	3,209
Sown after one crop of grain	1,729	2,919
Sown after two crops of grain	1,994	3,032 manured

It will be noted that seeding down after grain decreased the yields of hay the following year by from 700 to 1000 pounds as compared with seeding down on summerfallow. In comparing seeding down after the first crop of grain with a nurse crop with seeding down after the second crop, it will be noted that the stage in the rotation at which the grass was seeded made no difference. In fact, the yield is heavier after the second crop of grain. This bears out our experience on some of our rotation fields. We have seeded down twenty-acre fields for a number of years with the third crop of grain after summerfallowing and have never failed to secure a catch. This rotation was comparatively free from weeds.

Seeding down with a nurse crop decreased the yield on an average in the first crop of hay by 1200 pounds per acre, but in the second and third crops the influence of the nurse crop was not noticed.

The time that grass can be left will no doubt vary in different districts. At Scott there is practically no difference in yields in the second and third crop yields. This would indicate that in dry districts where it is difficult to secure a catch it may be advisable to leave Western Rye Grass for a third season.

Out of a number of rotations suggested in various publications I have listed the following three: The first is recommended for Manitoba, the second is the main crop rotation on our own station and the third has done the best on irrigated land at Lethbridge:

Manitoba Rotation	*Scott Rotation*	*Irrigated Land Rotation*
First Year—Inter-tilled crop and summerfallow	First Year—Summerfallow	First Year—Alfalfa
Second Year—Wheat seeded down to grass	Second Year—Wheat	Second Year—Barley and Alfalfa Seeding
Third Year—Hay	Third Year—Wheat or oats	Third Year —Oats
Fourth Year—Pasture until after haying; then break up.	Fourth Year—Oats seeded down	Fourth Year—Wheat
Fifth Year—Wheat	Fifth Year—Hay	Fifth Year—Potatoes
Sixth Year—Oats	Sixth Year—Pasture	Sixth Year—Alfalfa
		Seventh Year—Alfalfa
		Eighth Year—Alfalfa
		Ninth Year—Alfalfa
		Tenth Year—Alfalfa

We might consider the first of these rotations suitable for a district with a good supply of moisture; the last one would be for the drier districts. These are both adaptable to fairly large farms. The reason that summerfallow substitutes are not suggested at Scott is that corn does not do well. Sunflowers and roots grow later in the season than corn and appear to use up too much moisture to allow a profitable grain crop to follow. A whole summer is required at Scott to summerfallow sod land in order to permit storing the moisture for succeeding crops and to allow the sod to decompose.

Some other rotations that may be considered are as follows:

Sweet Clover Rotation

First Year—Summerfallow.

Second Year—Wheat, one-half field seeded down to sweet clover.

Third Year—Half field oats, half field sweet clover.

All rotted manure available ploughed under in spring as preparation for oats.

Fall Rye Rotation

First Year—Summerfallow.

Second Year—Wheat—fall rye seed sown with wheat for one-half the field.

Third Year—Half field oats—half field fall rye.
All rotted manure available to be ploughed under in spring as preparation for oats.

These rotations are presented as a few types that may be of practical use on some farms and with modifications may be adapted on others. They are not suggested as rotations that may be permanently employed, but rather as makeshift crop arrangements that are likely to be adopted by farmers who are seeking some systems that they can put into immediate use.

A Course to Train Specialists in Agronomy

By D. W. ROBERTSON

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In the last few years there has been a movement to standardize work in the colleges of the United States and Canada. Much work has been done along this line and many suggestions have been offered.

I will endeavor to present the outline of a course suitable for specialists in the various branches of agronomy.

To do this subject justice one should be familiar with the limitations of farming in the different sections of the United States and Canada. Climatic limitations of crops should be considered, and the continent would have to be divided into areas of climatic limitation and emphasis lain on the type of farming suitable to these areas by colleges situated in them. In general, Canada could be divided into two areas where a general type of farming can be followed: (1) The prairie region, where large tracts are farmed by one man and where dry farming methods may be used; (2) Group two would include Eastern Canada and the Pacific Coast, where moisture is plentiful in most places and smaller areas are farmed intensively.

The aim of agronomy courses for such an area should be to give a fundamental training in the junior years. This would enable the student to specialize at any institution in his final year, provided he had gained his required credits up to that time. He would thus be able to fit himself for whatever type of farming or research he hoped to follow.

Before entering upon the outline of a course to train specialists in agronomy, I should like to justify such a course. Specialized training is becoming more in demand in all phases of work. The early naturalists—Darwin, Agassiz, and many others—knew all that was to be known in their day. They were geologists, zoologists and botanists. Today, in the field of botany, we have specialists in several lines—plant physiologists, cytologists, taxonomists, pathologists, ecologists, etc. In agriculture we have similar specialization. The early agriculturists were botanists, cerealists, agrostologists, animal husbandrymen, etc. Today we have agronomists who still deal with several phases of crop production. However, in soils, which is included in agronomy, we have many specialists—chemists, bacteriologists, soil surveyors and physicists. Many other branches of agronomy could be broken up into specialized fields, but I will not take time to outline them. In extension work, in which a worker at one time had to be a jack-of-all-trades, we are now finding specialists who aid the agricultural agents in organizing their work. In many colleges you will find extension specialists in practically all the different lines of agriculture.

Requirements

The first difficulty is to decide what are the requirements for a degree student in agriculture. We will all agree that the entrance requirement should be equal to those required for the B.A. degree. As to the practical requirements, I think one year on a farm should be required before graduation. In looking over the calendar of the College of Agriculture of the University of Saskatchewan I find that a student is required to have one year on the farm from seeding to harvest, which would fulfill the requirement for an agronomy student. In Colorado similar experience is required.

Experimental Training

This is an important matter to consider in some institutions. Where the term is too short to allow the student to do some practical experimental work, a summer session should be required before graduation. This would allow the student to become familiar wth experimental methods.

Courses in Agronomy

In outlining such courses, an attempt has been made to give a brief description which will allow the construction of courses suitable to different conditions, but which will include all the fundamental points. To do this, I have first divided agronomy into three main groups—crops, soils and plant breeding.

Outline of Subjects Under the Special Group Headings

CROPS

1. *Cereal Crops*—A study of the more common crops, their adaptation, use and methods of culture. An elementary course.

2. *Forage Crops*—A study of the important grass and forage crops, their adaptation, use and methods of culture.

3. *Advanced Crops*—A more detailed study of the various agricultural crops, their classification, identification, etc.

4. *Miscellaneous Crops*—Common crops grown in other parts of the world, but not considered of enough importance to be included in 1 and 2.

5. *Milling and Baking Tests*—An advance course in milling and baking of special value to the plant breeder. Common tests used in flour laboratory and a study of by-products of farm products.

6. *Grain Judging and Market Grades of Grain*—A course in which students may become familiar with the market requirements and laws and the judging of grain and soil products by methods used at the agricultural fairs.

7. *Experimental Technique and Management*—Methods used in experimental work by the different experimental stations.

Seminars—Special problems.

SOILS

1. *Soils*—Origin, physics and chemistry of soils in their relation to agriculture.

2. *Meteorology and Climatology*—Atmospheric conditions influencing crop production, rainfall, humidity, temperature, etc.

3. *Soil Biology*—A study of the soil bacteria, protozoa, algae and fungi in their relation to crop production and management.

4. *Soils Laboratory*—Physical and mechanical properties of soils in their relation to tillage, soil moisture, water application and crop growth.

5. *Soil Management*—Influence of fertility, rotation and different systems of farming on the fertility of the soil.

6. *Soil Investigation*—Systems of soil investigation, sources of error and method of control.

7. *Soil Analysis*—Physical and chemical analysis of soils.

8. *Soil Survey*—Methods and classification of soils used by the United States Department of Agriculture.

PLANT BREEDING

Plant Breeding—An introductory course dealing with the fundamental principle of development, the laws of heredity and the application of the laws to the improvement of living things.

Farm Crop Improvement—The application of genetic principles to the improvement of crops.

Plant Breeding Seminar—Special problems.

The Number of Credit Hours Required for Degree Work

Most colleges require about 130 to 150 hours, and such a requirement is considered in outlining the following courses:

DISTRIBUTION OF CREDIT HOURS

Crops Group	Credits	Soils Group	Credits	Plant Breeding	Credits
1. Cereal Crops	3	1. Soils	3	1. Plant Breeding	3
2. Forage Crops	3	2. Meteorology and Climatology	2	2. Crop Improvement	4
3. Advanced Crops	3	3. Biology	3	3. Seminar	1
4. Miscellaneous Crops	1	4. Soils Laboratory	3		
5. Milling and Baking Tests	2	5. Soil Management	3		
6. Judging and Market Grades	2	6. Soil Investigation	1		
7. Experimental Technique	2	7. Soil Analysis	3		
8. Irrigation Farming	3	8. Soil Survey	2		
9. Seminar	1	9. Seminar	1		

The general distribution and prerequisites of study are very important. In distributing the courses of study over a college course, several matters should be considered. Assuming that certain general requirements are necessary for any student graduating in agriculture, the arrangement of basic sciences and their major and minor course should be considered. Many colleges require general botany and general chemistry as prerequisites for an agronomy course, and I think rightly so. However, this has one drawback—that of not interesting the student in some special line and giving him a chance to pick his major subject. For this reason some educators advise giving a crops and soil course in the freshman year.

Prerequisites for Agronomy Subjects

Crops Group

Cereal Crops—
General Botany

Forage Crops—
Cereal Crops

Advanced Crops—
Forage Crops
Plant Pathology
Botany (Taxonomy)

Miscellaneous Crops—
Advanced Crops

Milling and Baking Tests—
Organic Chemistry
Inorganic Chemistry
Qualitative Analysis
Quantitative Analysis

Judging and Market Grades—
Forage Crops

Experimental Technique and Management—
Advanced Crops
Soils
Geometry and Trigonometry

Soils Group

Soils—
Chemistry
Physics
Plant Physiology

Meteorology and Climatology—
Physics

Soil Biology—
Plant Pathology
Soils
Bacteriology

Soils Laboratory—
Soils

Soil Management—
Farm Management
Forage Crops
Soils

Soil Investigation—
Colloidal Chemistry
Soil Biology
Forage Crops

Soil Analysis—
Physics
Soils
Inorganic Chemistry
Organic Chemistry
Quantitative Analysis
Qualitative Analysis

Soil Survey—
Geology
Soil Analysis

Plant Breeding Group

Plant Breeding—
General Botany
Cereal Crops
Plant Pathology

Farm Crop Improvement—
Cytology
Plant Physiology
Plant Breeding
Geometry and Trigonometry

Seminars—
Course allied to problem

Distribution of Studies—Four-Year Course

Crops Group

Second Year—

Cereal Crops	3
Soils	3
Meteorology and Climatology	2
	8

Soils Group

Cereal Crops	3
Soils	3
Meteorology and Climatology	2
	8

Plant Breeding Group

Cereal Crops	3
Soils	3
Meteorology and Climatology	2
	8

Third Year—					
Forage Crops	3	Forage Crops	3	Forage Crops	3
Judging and Market Grades	2	Soils Laboratory	3	Soil Management	3
Soil Management	3	Soil Management	3	Plant Breeding	3
Plant Breeding	3	Plant Breeding	3		—
	—		—		9
	11		12		
Fourth Year—					
Advanced Crops	3	Soil Biology	3	Milling and Baking Tests	2
Miscellaneous Crops	1	Soil Analysis	3	Irrigation Farming	3
Milling and Baking	2	Exp. Technique	2	Crop Improvement	4
Exp. Technique	2	Soil Survey	2	Advanced Crops	3
Irrigation Farming	3	Soil Investigation	1	Miscellaneous Crops	1
Drainage	2		—		—
	—		11		13
	13				
Seminar	1			Seminar	1
	—		—		—
	33		31		31

Discussion

In summing up, there are several points I wish to bring out. In looking over the distribution of studies you will see that any one of the three groups would fit a student as a teacher in agronomy. And with some extra training he could specialize in any other group if required. Another point I wish to bring out is that a specialist in any one of the groups has sufficient foundation for advanced work in that group. I should also like to emphasize the fact that a student should take special work in one of the sciences in preparing himself for this work. For instance, students specializing in crops and breeding would take more botany than is required and in soils more chemistry than is required. If intending to pursue graduate study, more mathematics should be taken.

Laboratory and Field Germination Tests

By W. H. WRIGHT

Dominion Seed Branch, Calgary, Alberta

Cereals and Clovers

Probably every seed analyst who has done much testing of seeds for germination qualities has asked himself many times: "What is the value of a laboratory test? What does it mean to the farmer?" In other words, what percentage of seeds which germinate in the laboratory would produce healthy plants in the fields?

It was in the hope of obtaining some information on this subject that some preliminary work was started last summer in the garden of the Seed Branch at Calgary. Unfortunately, the work was not commenced until the second week in June, owing to a change in quarters being made which upset the routine work of the Branch.

The methods used in making the necessary tests of oats, wheat, and barley were conducted in the same manner. The seeds used were taken from samples which had been received in the ordinary course of events, either from the trade or from the farmers, which had been germinated in the usual manner as soon as they entered the laboratory. These samples were taken so as to cover a range of from 100 to 9 per cent germination, as shown by the original test, but were not in any way selected in the strict sense of the word, as we simply went through our files, taking the first half dozen 100 per cent germination, and so on, until the lowest possible percentage had been obtained.

On the same day that the field test was commenced a check test was started in the laboratory by the ordinary methods employed at Calgary. Two "one-hundred counts" of each sample were made. The oats and barley were planted in cardboard boxes containing 150 grams of soil, given a preliminary watering with 65 grams of water and placed in a dark room with the temperature running between 18 and 20 degrees C. The wheat was germinated between blotters at the same temperature. The counts were made on the sixth and twelfth day respectively. This check test was made in order to be sure that the seed suffered no deterioration during the period of storage. It was interesting to note in some of the check tests a decided improvement over the original. This was more common where the original test showed less than 60 per cent germination than where better results had been obtained.

The soil in which the field tests were made is light sandy loam which has been under garden crops for several years and has been well fertilized. In this soil, three "one hundred lots" of each sample of seed were planted in drills six inches apart and from two to two and one-half inches deep. The seeds were placed about an inch and one-half apart. As the soil was as dry as dust, it was moistened before the planting was done, and watered twice after planting. On account of the nature of the soil, the warm, even temperature and the watering, these tests were made under rather ideal conditions. The plants were counted on the twelfth and fifteenth days, being then about two and a half to three inches high. These were apparently perfectly healthy, and there was no reason to suppose that under normal conditions they would not have developed and matured seed. However, they were not given a chance, as they were carefully removed from the soil and the plots watched for any belated plants which might appear. Very few plants were found after fifteen days, the greatest number in any one row being three. Some of those which ultimately did show above the surface of the ground were noticeably weak and spindly.

A summary of the results of these few tests shows that oats which germinated between 100 per cent and 70 per cent under laboratory conditions gave an average of 10 per cent fewer plants in the field than would be indicated by the number of germinable seeds, whereas wheat and barley produced 5 per cent and 4 per cent fewer respectively. When germination in the laboratory was below 65 per cent a greater variation was noticed in the number of plants produced. We found that oats produced from 14 to 50 fewer plants than might be expected, the average being 21 per cent lower than the number of seeds which germinated in the dark room. Wheat averaged 12 per cent and barley 22 per cent below the laboratory check tests.

Similar tests were attempted with alsike, red clover, alfalfa, sweet clover, vetches and mangels. An untimely hail storm completely destroyed the first seedings as the young plants were just nicely above ground. A second attempt was made during the hot, dry weather, and the results may not prove very satisfactory. However, they were worth recording. To summarize, the clovers made poor showing in the field tests, the number of plants produced being far less than the number of seeds which germinated in tests conducted in the laboratory by the usual methods, as the following table will show:

		Per Cent.
Alsike Clover	Average germination in laboratory check test	69
	Plants produced	24
Red Clover	Average germination in laboratory check test	73
	Plants produced	47
Sweet Clover	Average germination in laboratory check test	51
	Plants produced	23
Alfalfa	Average germination in laboratory check test	69
	Plants produced	52
Vetches	Average germination in laboratory check test	77
	Plants produced	77
Mangels	Average germination in laboratory check test	62
	Plants produced	26

It might be interesting here to cite for comparison the results of similar work done by W. O. Whitman, of Bozeman, Montana, published in the report of the Association of Official Seed Analysts of North America, 1921.

The soil selected for making the field tests was a rather heavy clay loam of uniform nature. The results obtained with some of the seeds tested are as follows:

	Germination in Laboratory	Germination in Field	Difference
Wheat	97%	74%	23%
Alfalfa	71%	24%	47%
Sweet Clover	50%	17%	23%
Red Clover	59%	21%	38%

The differences between the laboratory tests and the field tests made in Calgary were: wheat, 10 per cent; alfalfa, 17 per cent; sweet clover, 28 per cent; red clover, 28 per cent.

To quote Mr. Whitcomb: "These data are considered only as preliminary and are not to be accepted as being conclusive. Their greatest value lies in their application to the problem under consideration in planning future work in correlating laboratory tests of seed germination with field tests." Nevertheless the results obtained from these tests tend to prove that seed which germinates between 100 per cent and 70 per cent in the laboratory may be expected to produce on an average 10 per cent fewer plants in the field. If possible these comparisons will be carried on for two or three years in the hope of obtaining some definite results.

Grass Seeds

Compared with the cereals, the correlating of laboratory and field tests of grass seeds will be a much more difficult thing to accomplish, but is just as important or more so. At the present time an attempt is being made in the Winnipeg and Calgary laboratories to arrive at some thoroughly reliable method for carrying out germination tests of each of the varieties of grasses commonly sent in for germination. The grasses are: timothy, awnless brome grass, Western rye grass, blue grass, fescues, red top, perennial rye grass, with an occassional sample of orchard grass, crested dog tail and Italian rye grass.

During the summer these grasses were tested in the above mentioned laboratories by many different methods. In Calgary thirteen were used. Time will not allow, nor is it necessary to go into the details at the present time. However, we have been able to decide on two methods for each grass, which will be used for the remainder of the season. This does not mean that we are perfectly satisfied with all the methods chosen, as perplexing and unaccountable results are often obtained.

Timothy often illustrates this very well indeed. Ordinarily at Calgary timothy seed is germinated in soil in a dark germinator, with a temperature ranging from 20 to

30 degrees centigrade, while at Ottawa and Winnipeg it is tested between blotters at the same temperature. Nine samples out of ten will give excellent results by these methods, or if a poor result is obtained, it is found that the seed cannot be made to germinate by any other method. The tenth sample may do extremely poorly in soil or blotters, but when put under the bell jar in the light, at room temperature which is generally about 23 degrees centigrade, an increase of 25 per cent germination is often shown. A sample tested in the early part of December gave an average of 27 per cent germination in the soil and 98 per cent under the bell jar. This is rather an extreme case, but many times the samples have been raised from Grade No. 3 to Grade No. 1 by this method.

The question we are asking ourselves is whether or not the bell jar gives a fair test. As some of you may not have seen the bell jar method, which, by the way, was introduced in Calgary by Mr. Fryer, we have prepared a small chart. You will see that the apparatus is quite simple, consisting of two disks of blotting paper (one of which is provided with a blotting paper wick), a cup, and a bell jar. The cup is nearly filled with water and covered with a blotter provided with a wick—the latter, of course, being in the water. The second disk is placed on top of the first, and on this the timothy seed is sprinkled, the whole being covered with the bell jar. In this method the timothy receives much more moisture than when planted in the soil or between blotters unconnected with moisture pan. A film of water can be seen on the surface of the upper blotter, whereas when the timothy is planted in soil in a small cardboard box, which has holes punctured in the bottom, and which stands on blotters, there can be no chance of excess moisture accumulating.

Which method will give us the best idea of the true germination value of the seed under natural conditions is the problem which yet remains to be solved. As far as we can see, the only way is to grow the seed in the open. The great difficulty is to be sure that there is no grass seed already in the soil of the plot. This brings up the difficulty of soil sterilization, and it is this point which we would like discussed at this meeting, and we can assure you that any suggestions will be very very thankfully received. Once this obstacle is overcome there is no doubt that the field tests of grasses will give very valuable information as to the actual value of laboratory tests, and so decide which test can be adopted as the standard method for each variety of grass.

Wheat Stem Rust From the Standpoint of Plant Breeding

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Introduction

In the spring wheat section of the United States and in certain parts of Canada the black stem rust *(Puccinia graminis)* causes enormous losses and is one of the chief

(1) The data presented in this paper were obtained in co-operative investigations between the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, and the Department of Agriculture of the University of Minnesota.

The writers are under obligation to M. N. Levine and O. S. Aamodt for unpublished data on phases of the problem which they are investigating as a part of the general co-operative project. Published with the approval of the Director, as Paper No. 300, Journal Series, of the Minnesota Agricultural Experiment Station.

causes of low yields. The importance of the rust problem may be emphasized by a consideration of the acre yields obtained in Minnesota during the ten-year period from 1911 to 1920 inclusive. During these ten years black stem rust was epidemic in 1916, 1919 and 1920. The average yield for these years was 8.6 bushels per acre, while for the seven years in which rust was not a major factor the average yield was 15.4 bushels. Apparently rust epidemics are becoming more frequent. Evidently, therefore, rust must be controlled or the larger part of the spring wheat section in the United States must go out of the business of producing spring wheat.

There are two major methods by which rust losses can be reduced. The relation of the barberry, at least to local rust epidemics, has been clearly demonstrated, and the eradication of the barberry may be expected to reduce materially the amount of stem rust. Because of obvious difficulties, many years probably will elapse before the barberry is entirely eradicated. Even after all barberries are removed there is no sure proof that stem rust will be controlled entirely. For this reason it appears that plant breeding should be continued vigorously with the expectation that the rust problem may be controlled through a combination of the two modes of attack—the breeding of resistant varieties and the removal of the barberry.

The purpose of this paper is to review briefly the present methods which are being employed in Minnesota, in a co-operative attempt by plant breeders and plant pathologists to produce resistant spring wheats.

Review of Previous Studies in Relation to the Control of Plant Diseases Through Plant Breeding

In producing disease-resistant varieties, the plant breeder is faced with two considerations; the biologic stability of the parasite and the mode of inheritance of disease resistance.

Stability of the Rust Parasite—The importance of a knowledge of the stability of the pathogene is apparent. If the disease-producing organism can rapidly acquire the ability to attack previously resistant varieties, the plant breeder faces a hopeless task.

Recent pathological studies, made at the Minnesota station, have furnished valuable information regarding the plasticity of biologic forms of the stem rust parasite. Before presenting the present conception of biologic forms, a brief review of earlier views will be of interest.

Eriksson (1894) discovered that there were biologic forms of *Puccinia graminis* on the different groups of cereals. He was of the opinion that these forms may have originated as a result of long-time association with particular host plants. Somewhat later Ward (1903), in an investigation of the brown rust of bromes (*Puccinia dispersa*, Erikss) concluded that the parasitic capabilities of a rust form could be changed rapidly through association with certain hosts. In cases where the rust could not be transferred directly from one species of Bromus to another, the rust, when first placed on a third species which it was capable of infecting, was so changed that it acquired the capability of infecting the normally immune variety. Hosts which increased the infection capabilities of the pathogene were called bridging hosts. Salmon (1904) found evidence of bridging hosts which increased the host range of *Erysiphe graminis* D.C. on various species of Bromus, and Freeman and Johnson (1911) concluded that barley increased the host range of *P. graminis*.

Pole Evans (1911) obtained results which apparently showed that wheat hybrids changed the infection capacities of wheat stem rust. He stated that the hybrid between a susceptible and an immune variety changed the rust to such an extent as to enable it not only to attack the susceptible variety more severely but even to infect the immune parent. Stakman and co-workers, however, in recent years, have made careful studies of the question with *Puccinia graminis* (Stakman, Piemeisel and Levine, 1918) (Stakman,

Parker and Piemeisel, 1918) and have not obtained evidence of bridging hosts. The results of their studies have led to the conclusion that the stem rusts of cereals are constant in their infection capabilities and are not changed quickly through their association with cereal hosts. Careful studies did not corroborate the views of Freeman and Johnson that barley acted as a bridging host. Unlike the results of Pole Evans, hybrid wheats were not found to increase the infection capabilities of rusts.

It has been shown, however, that there are numerous racial strains[2] of the stem rust of wheat which can be differentiated only by their action on various varieties. The studies were carried on in the greenhouse by inoculating seedlings of pure line wheat varieties with cultures of stem rust. The determination of the number of biologic forms is made possible by the use of a series of differential varieties as host plants. The wheat varieties used at Minnesota are representatives of five wheat species groups. The varieties used are as follows:

Triticum vulgare—Marquis, Kanred, Kota.

T. compactum—Little Club.

T. durum—Arnautka, Mindum, Speltz Marz, Kubanka, Acme.

T. dicoccum—White Spring Emmer, Khapli.

T. monococcum—Einkorn.

Five separate types of infection are recognized under greenhouse conditions, slight deviations being noted by plus and minus signs. These five symbols have been developed by Stakman and Levine, and they have been found to represent inherited differences. The explanation of these five symbols is made in Table 1 (also see Fig. 1).

TABLE I.

Explanation of symbols used to indicate rust reaction of various biologic forms on wheat varieties and hybrids.

0. *Immune*—No uredinia developed; hypersensitive flecks sometimes present.

1. *Very resistant*—Uredinia minute and isolated; surrounded by sharp, continuous hypersensitive, necrotic areas.

2. *Moderately resistant*—Uredinia isolated and small to medium in size; hypersensitive areas present in the form of necrotic halos or circles; pustules often in green, but slightly chlorotic islands.

3. *Moderately susceptible*—Uredinia medium in size; coalescence infrequent; development of rust somewhat sub-normal; true hypersensitiveness absent; chlorotic areas, however, may be present.

4. *Very susceptible*—Uredinia large, numerous and confluant; true hypersensitiveness entirely absent, but chlorosis may be present.

X. *Heterogeneous*—Uredinia very variable; often including all types and degrees of infection on the same blade; no mechanical separation possible; on re-inoculation small uredinia may produce large ones and vice versa.

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(2) Stakman and Piemeisel, 1917; Levine and Stakman, 1918; Melchers and Parker, 1918; Stakman, Levine and Leach, 1919; Newton, 1920.

Fig. 1—Types of infection caused by different biologic forms of *Puccinia graminis tritici* on Marquis wheat in the greenhouse. From left to right, types of infection are 0, 1, 2, 3, and 4, respectively.

Through a correlation of field and greenhouse studies, the meaning of these symbols, from the viewpoint of commercial field resistance, has been rather accurately estimated. The plants with 0 type of infection in the greenhouse are also immune in the field, and varieties which give a 1 or 2-type of infection in the greenhouse are highly resistant in the field. Plants with the 3-type of infection in the greenhouse show some resistance in the field, although those with a 3-type of infection in the greenhouse probably are susceptible under field conditions. A variety with a 4-type infection in the greenhouse is highly susceptible in the field.

When a rust culture from a locality is collected, its infection capabilities are determined by inoculating seedlings of the various differential wheat hosts and determining the manner of reaction. If the same biologic form has been obtained previously, the results are rechecked by a second series of inoculations. Sometimes mixtures of several biologic forms are obtained, in which case repeated inoculations are necessary in order to separate them.

Several racial strains of rust have been obtained which, especially on durums, may produce different types of infection on the same plant. This is called an X reaction. Spores from either the large or from the small pustules again produce an X reaction on reinoculation. It is probable that many of the wheat strains which show the X form of reaction would be resistant under field conditions.

Stakman and others (1918) have suggested three possible causes of the origin of biologic forms[3]. These are gradual adaptation, mutation and hybridization.

No evidence of mutation or gradual adaptation has been obtained as a result of numerous and extensive experiments both with the uredinial and aecial stages of many biologic forms. The practical importance of knowing whether new forms are constantly arising would seem to warrant further studies.

It appears that if a biologic form was homozygous for its inheritance factors that no change should be expected during its life history in any state unless a cross occurred between two biologic forms. This could conceivably take place upon the barberry. If, however, a biologic form was heterozygous for its inheritance factors it would seem that segregation might occur at the time of teleutospore formation in the spring. Two or more racial strains might then occur from a single form. The possibility that the forms which give X reactions are heterozygous and therefore somewhat less stable in their manner of reaction seems worth considering. A promising mode of determining a possible origin of the numerous biologic forms would appear to be to study the stability of a series of forms immediately after they had been grown on barberry. Definite hybridization studies might be made, although some difficulties of crossing biologic rust forms are apparent.

More detailed surveys of the spring wheat area should be made in order to determine the number and location of the various forms. As fast as new forms appear they should be cultured and made available for the breeding studies. This is the present plan which has been adopted in Minnesota.

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[3] A total of thirty-seven has been found by Stakman and Levine and of these twenty-one are Northwest forms.

Production of Disease-Resistant Plants—During recent years many successful attempts to control plant diseases through plant breeding have been made. For the various wilt diseases selection of resistant plants has frequently given very valuable results. The early work of Bolley (1901) in North Dakota, who produced wilt-resistant flax by selection, is well known. Wilt-resistant tomatoes have been selected by Edgerton (1918) and Darst (1918). The production of cabbage resistant to yellows by Jones and others (1915, 1920), in Wisconsin, is of great economic importance. By selection of seed from resistant individual plants it was possible to obtain resistant races of high quality from all varieties tested.

Gaines (1920) has studied the inheritance in wheat of resistance to bunt (*Tilletia tritici*). Although the results were somewhat complex, bunt resistance was found to be an inherited character. It seemed reasonable to conclude that bunt resistance could be combined with any series of desirable agronomic and botanical characters.

Extensive reviews of various studies of the inheritance of resistance to disease are not necessary. Biffin (1907) found the inheritance of host reaction to stripe rust (*Puccinia glumarum*) to be a simple Mendelian character with susceptibility a dominant over resistance, while Nilsson-Ehle (1911) obtained segregation in crosses between resistant and susceptible forms but found that the results could be explained only by the multiple factor hypothesis. Resistance to stem rust of oats was shown by Garber (1920) to behave as a simple Mendelian character, but in this case resistance was a dominant over susceptibility.

These studies and others have shown that disease resistance is inherited in the same manner as are other characters. In the light of these studies the plant breeder who would breed rust-resistant wheat is faced with the problem of obtaining all biologic forms prevalent in the locality in which the improved variety is to be grown. Wheat varieties which are resistant to particular biologic forms should then be produced. The co-operative breeding studies now being made in Minnesota may be used to illustrate this mode of attack.

Present Methods of Breeding Wheat Resistant to Stem Rust

The Use of Biologic Forms—Fairly extensive surveys of the Northwest have been made and a considerable number of biologic forms have been found. These forms are then kept available for use in the breeding studies. The value of the greenhouse, in breeding wheat for rust resistance, is very great. Ten to fifteen F_3 seedlings planted from an individual F_2 plant and inoculated with a known biologic form are sufficient to determine the reaction of the F_3 family to the particular rust form. Before planting seeds of an F_2 plant in the field it is possible to determine the genotypic nature of the parent plant for rust reaction. The necessity of close co-operation between the pathologist and plant breeder cannot be over-estimated.

A list of the number of Northwest biologic forms with a statement of the manner of reaction of particular parental varieties will help materially to show the method now being used in Minnesota. (See Table II.)

TABLE II

Northwest biologic forms and the manner of reaction of certain wheat varieties to these forms.

Biologic Form Number.	Wheat Varieties Used as Parents. Kanred	Kota	Iumillo	Mindum	Khapli
I	0	..	0	1	1
III	..	..	0	0	1
V	0	3	..	..	0
IX	0	..	..	..	0
XI	..	..	..	..	1
XII	3	..	..	1	1
XIII	3	3	..	3	1
XIV	1	0	..	..	1
XV	..	..	..	..	1
XVI	0	1	..	..	1
XVII	0	..	0	..	1
XVIII	..	3	0	0	0
XIX	0	3	0	..	1
XXI	0	..	..	..	0
XXII	.	3	..	..	0
XXIV	0	1	..	..	0
XXIX	0	..	0	X	1
XXX	0	..	..	X	0
XXXI	..	1	..	X	0
XXXII	..	3	..	X	1
XXXVI	0	..	..	..	0

The more promising varieties of wheat which are being used in breeding investigations are listed in Table II and their reaction to Northwest biologic forms is indicated. The various degrees of resistance and susceptibility are shown by indicating only those cases in which the variety is known to have definite resistance to certain biologic forms. The reaction of all five varieties, except Iumillo which so far has proven resistant to all forms, has been tested with each of the twenty-one known Northwest biologic forms. With the exception of Iumillo, the blank spaces represent reactions of 3+ to 4, which indicates susceptibility under field conditions.

From a consideration of Table II it will be noted that Kanrad winter wheat is immune to eleven of these twenty-one biologic forms, very resistant to one form and only moderately susceptible to two other forms. Kota is very resistant to form XXXI, which attacks Kanred, and only moderately susceptible to forms XXXII, XVIII and XXII, to which Kanred is very susceptible; Iumillo adds resistance to biologic forms III and XVIII, which attack all varieties of *T. vulgare.* This leaves only forms XI and XV, to which Khapli is immune and very resistant respectively. It should be noted that Khapli is resistant to all biologic forms.

In the light of the known reaction of these various wheat varieties, we may next turn to a consideration of the breeding results.

Crosses within the T. vulgare Group—Two series of crosses within this group are being studied. Because of its immunity to eleven biologic forms and resistance to three others, Kanred winter wheat is very important. Crosses between Kanred and Marquis have been studied through the fourth generation. The first generation of the Kanred-Marquis cross was planted as a winter wheat in the fall of 1918. It survived the winter, although the color of the plants was somewhat yellowish green early in the spring

of 1919. A considerable quantity of seeds was obtained, and in the spring of 1920 approximately 6,000 F_2 seeds were planted.

On University Farm, winter wheat, when planted in the spring, produces only an occasional late head which rarely, if ever, matures seed. The F_2 population was classified, according to time of heading, into nine groups—group 1 representing those plants which headed as early as Marquis, group 9 those which appeared to be true winter plants, while groups 2 to 8 inclusive contained plants which headed at various intermediate periods. Representatives of these F_2 heading groups were planted in the greenhouse in the winter of 1920-21, and F_3 seedlings were inoculated with several different biologic forms to which Kanred was immune. Segregation for rust reaction was obtained in each of the seven groups for time of heading. There was no apparent correlation between any heading period and segregation for rust reaction.

The results showed very clearly that rust resistance behaved as a simple Mendelian dominant. By using the reaction of F_3 seedlings, the F_2 plants were placed in three groups in the following ratios: 1, homozygous for immunity; 2, heterozygous for rust reaction, there being approximately 3 immune to 1 susceptible plant; 3, homozygous for susceptibility.

F_2 plants were then selected from the earlier heading groups on the basis of their rust reaction, and numerous F_3 families were grown during the 1921 crop season. Several of these F_3 families proved homozygous for spring habit as well as for rust reaction.

The F_3 plants were harvested individually and all plants were selected which appeared at all promising for agronomic plant and seed characters. The reaction of seedlings from many of these plants has already been tested this winter for known biologic forms of stem rust to which Kanred is immune. Families which appeared homozygous for rust immunity in the 1921 greenhouse test have again proved immune. (See Fig. 2.)

The investigation has now been continued for a sufficiently long period to justify the conclusion that resistance to all forms of rust to which Kanred is immune is inherited as a single genetic factor.

One F_3 family from an earlier cross made by the United States Department of Agriculture appeared promising in the season of 1920, and it was homozygous for immunity to certain biologic rust forms. It also appeared promising in a preliminary rod-row test made this last year. Some of the Marquis-Kanred crosses also apparently were much more resistant to *Helmintho-sporium sativum* than the Marquis parent.

Crosses between Kota and Marquis have been made and an F_2 generation was grown in 1920. Some of the plants appeared very promising for plant and seed type. They will be studied this winter, particular attention being paid to those biologic forms to which Kota is resistant and to which Kanred and the Kanred-Marquis hybrids are susceptible. F_3 families which are resistant to these biologic forms in the greenhouse will be crossed in 1922 with the Marquis-Kanred resistant forms with the hope of obtaining wheats which are resistant to all forms to which Kota and Kanred are resistant. This shows the basis for the breeding studies now being carried on at Minnesota.

The attempt is being made to develop by this synthetic method a wheat variety which is resistant to all forms of stem rust. The mode of reaction of two biologic forms of rust on F_2 plants of crosses between varieties which react reciprocally to these two rust forms has been studied by Puttick (1921) at the Minnesota station. Some F_2 plants were obtained which were highly resistant to both rust forms.

Durum-vulgare Crosses—Before Kanred and Kota were available for use as rust-resistant parents, various durum wheats were crossed with common varieties. The first crosses of this kind were made under the direction of Freeman and Johnson about 1908. Preliminary studies carried on by these workers and their assistants from 1908

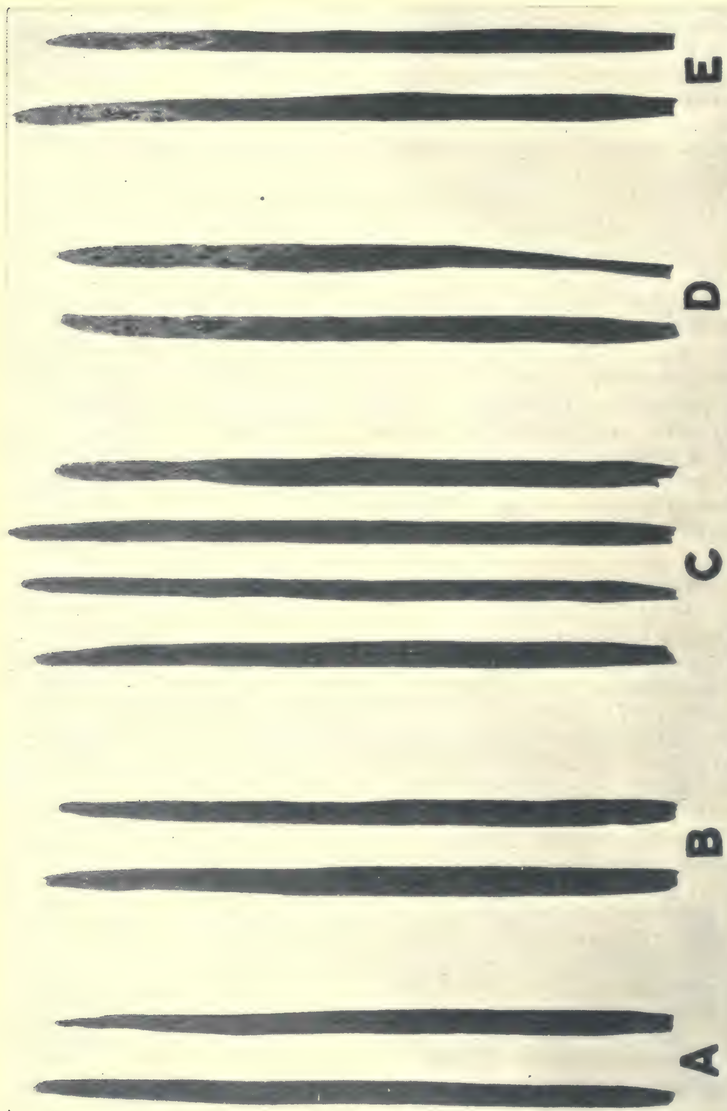

Fig. 2—Seedlings of Kanred, Marquis and F_3 families of the cross between Kanred and Marquis inoculated with a rust form to which Kanred is immune and Marquis susceptible. A—Kanred, immune. B—F_3 Kanred x Marquis, immune. C—F_3 Kanred x Marquis, segregating for susceptibility to rust. D—F_3 Kanred x Marquis, susceptible. E—Marquis, susceptible.

to 1915 showed that it was difficult to combine the resistance of durum wheats with the agronomic characters of common varieties.

From the results obtained from other plant-breeding studies it appeared that the proper mode of attack on this problem was to grow large F_2 and F_3 families of durum-common crosses, because, if there was genetic linkage between durum characters and rust resistance, this could perhaps best be overcome by using large numbers of plants. Accordingly, Iumillo and Kubanka 2,094 were crossed with Marquis. Over one thousand F_2 plants were examined and progeny of each were grown in F_3 under rust epidemic conditions. One or two F_3 families gave some plants which appeared of promise for common head type and for rust resistance (Hayes, Garber and Kurtzwell, 1920). Selections were made, and the following year some families again appeared rather promising. Progeny of the cross between Marquis x Iumillo have been grown under rust epidemic conditions for the last two seasons. An artificial epidemic was induced by spraying with known biologic forms of rust although the forms to which Khapli alone is resistant were not used. Some of the Marquis-Iumillo crosses appeared to be common wheats and they were highly resistant under field conditions while Marquis was very susceptible. (See Fig. 3.) Seedlings of one of the F_6 hybrid families were resistant to biologic form XVIII, and accordingly crosses were made between the Marquis-Iumillo hybrids and two of the better rust resistant Kanred-Marquis families. There was evidence of the X type of reaction in the Iumillo-Marquis crosses, although one family appeared resistant even though there was some variability in the size of the uredinia.

The results of these durum-common crosses show that high sterility must be expected from crosses of durum and common wheats. Some plants are obtained in F_2 which are entirely self-sterile while others are quite fertile.

Extensive studies of durum-common crosses have been made previously. Vilmorin (1880, 1883) found, in a cross between durum with common, that poulard, durum, spelt and common types could be expected in F_2. Tschermak (1913) obtained similar results when solid and hollow-stemmed durum and common varieties were crossed. Sterility has been mentioned by nearly all writers who have made crosses between these wheat species.

Linkage of characters has been found by Freeman (1917) in durum-common crosses and by Engledow (1914) and Biffen (1916) in crosses between *T. turgidum*, variety Rivet, and common fife wheat. From the standpoint of the plant breeder, it would appear that the production of large families is essential in crosses in which there is a linkage between the characters which it is desired to recombine. In the cross between Marquis and Iumillo linkage between durum head type and rust resistance was apparent. This linkage relation was overcome by growing rather extensive progenies.

Khapli in Relation to Stem Rust—It already has been mentioned that Khapli, an early variety of *T. dicoccum*, is resistant to all biologic forms of wheat stem rust. Accordingly, frequent attempts have been made to cross varieties of common wheat with Khapli. Some early crosses of Khapli with Marquis which were made by Parker were grown in 1916 at University Farm. Although the crosses were in the F_3 generation, they were very variable in type and did not appear at all promising. Subsequent experience indicates that this extreme variability was due to the high degree of self-sterility of the Khapli crosses. Progeny of hybrid plants which exhibit partial sterility often show large percentages of natural crossing.

Several Khapli-Marquis crosses were grown in the greenhouse in 1919, but, although the F_1 plants produced a few heads, no seeds were obtained. Accordingly, in 1920, extensive crosses were made between Khapli and Marquis and approximately three hundred seeds were obtained. These were planted in the plant-breeding nursery in 1921. Only a few seeds germinated, and the resulting plants were very small. The plan was

Fig. 3—At left, Marquis; at right, Iumillo; in centre, F_6 generation of Marquis x Iumillo which breeds true for common wheat characteristics and resistance to certain biologic forms of stem rust.

to pollinate these F_1 Khapli-Marquis crosses with pollen of various spring wheat varieties. Only two of the Marquis-Khapli crosses produced heads. The pollination of these with common wheats did not result in the production of seed. (See Fig. 4.)

Extensive studies led Tschermak (1914a, b) to make the following genetic classification of wheat species groups. Sterility and the possibility of crossing different groups were made the basis of the classification. (See Table III).

TABLE III

Wheat Species Groups

Group Composition	Einkorn Group	Emmer Group	Spelt Group
Stem species spelt wheats	*T. aegilopoides*	*T. dicoccoides*	*T. spelta*, wild form unknown.
Cultivated forms covered seed	*T. monococcum*	*T. dicoccum*	*T. spelta.*
Cultivated forms naked seed	Unknown	*T. turgidum* *T. polonicum* *T. durum*	*T. vulgare* *T. compactum*

Previous crosses between the covered emmer group with naked members of the spelt group have been partially fertile. The crosses between Khapli and *T. vulgare* have already been noted.

Because of the failure of Khapli-Marquis crosses to set seed in F_1, another mode of attack is being followed. Khapli has been crossed with several durum varieties, and the F_1 generation was very vigorous. Extensive F_2 generations will be grown, and plants of the durum type will be selected. Seedlings of these plants will then be tested, and their reaction to forms XI and XV will be determined. If durum wheats are obtained which are resistant to these biologic forms, they will then be crossed with some of the hybrids which are resistant to many other Northwest biologic forms. It seems probable that the desired result can be obtained by this means, because it already has been shown that by suitable crosses the resistance of durum wheats can be combined with the characters of common wheats.

Summary

1. The discovery of biologic forms of stem rust of wheat has placed the problem of breeding rust resistant wheats on a definite scientific basis. The occurrence of these forms furnishes a logical explanation for the conflicting views regarding the stability and adaptability of the wheat rust parasite.

2. Numerous tests of biologic forms in the uredinespore stage have furnished results which show that the individual forms are relatively stable.

3. Extensive tests with various biologic forms should be made to determine the possibility of genetic segregation at the time of formation of the teleuto spores. Forms which are heterogeneous and give the X type of reaction would appear to be especially favorable material for this study.

4. Disease resistance in plants is inherited in the same way as are other plant characters.

5. Further studies are necessary to determine the number and prevalence of biologic forms of stem rust. The forms obtained should then be used in definite attempts to build up wheat varieties which are resistant to all forms of wheat stem rust.

6. The production of resistant varieties of crop plants can best be obtained through co-operation of plant pathologists and plant breeders. Definite co-operation between

Fig. 4—At right, Marquis; in center, Khapli; emmer; and at the left, the F_1 Khapli-Marquis cross.

different research institutions would also aid in solving those problems in which two or more research institutions were interested.

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Discussion of Hayes and Stakman's Paper, "Wheat Stem Rust—from the Standpoint of Plant Breeding"

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Although the solution of the rust problem appears well within sight, much work remains to be accomplished. The problem is far larger than was realized at first. The present investigators need more assistance if they are to produce results quickly, and I believe we all agree that no time should be lost in combatting a disease which annually causes millions of dollars damage to the western wheat crop. Let us discuss the important phases of the problem.

Expensive barberry eradication campaigns are being conducted in some parts of the United States, yet there is no definite evidence that barberry removal will rid us of the rust plague. It is quite possible that our rust epidemics may be produced by spores brought up from the South by the wind. It is well known that *Puccinia graminis tritici*, the organism causing black stem rust on wheat, propagates itself throughout the winter in the South by means of summer spores (uredospores), and experiments have proved that these spores may remain viable several weeks. Stakman, working for the United States Department of Agriculture, demonstrated that fungous spores were carried in the upper air currents. This was done by means of spore traps exposed on aeroplanes. Rust spores, as well as various other kinds, were found at altitudes up to twelve thousand feet. We, in Western Canada, need exact information on the spore content of the upper air. Many hundreds of aeroplane flights are made each season at various places in the prairie provinces. At relatively little expense arrangements could be made for the carrying of spore traps at different times of the season and at various altitudes.

We understand that of the thirty-seven forms of *P. graminis tritici* now known, twenty-one were found in the northwestern spring wheat area. A number of these were picked up during the past season. There may be others of which we know nothing. In breeding wheat for rust resistance it is quite necessary to have data concerning at least all the forms which are present in the Northwest; otherwise, we may spend years breeding a variety resistant to known rust forms and then discover that it is susceptible to a hitherto unknown form.

The federal departments of agriculture of Canada and the United States have had surveys made for the collection of rust forms, but this work is by no means complete. With larger field and nursery staffs an adequately extensive collection of material could be made. *The men engaged in this work should co-operate closely*, use a standardized method of procedure, have frequent conferences and freely exchange material. The problem is not one that can be confined to one province or state, nor yet to one country. It concerns the whole northwestern prairie section.

In addition to the collection of different forms, we need detailed information regarding their distribution, prevalence and virulence. Possibly a district like Central Saskatchewan may not be troubled with some form which is very virulent in southern Minnesota. That being the case, it would not be necessary to consider that form when breeding a rust-resistant variety of wheat for the former locality.

Dr. Hayes spoke of the various crosses involved in the rust-resistance breeding work now being carried on at the Minnesota station. He mentioned the high percentage of linkage existing between durum character and rust resistance and the large amount of

sterility in durum-vulgare hybrids, making necessary the growing of very large populations of the second and third hybrid generations in order to secure desirable plants. This work is rapidly becoming too extensive for one station to handle. It is quite possible that a similar condition exists at other stations. Now, if the stations working on this problem could divide their material so that each would only need to handle one or two crosses, more rapid progress should result. Here again close co-operation with mutual exchange of material and ideas, standardization of methods and frequent conferences would be of great value.

Some of the spring wheat types selected from the Kanred-Marquis cross made at the Minnesota station were found to be much more resistant to root rot than Marquis. Recently wheat varieties resistant to covered smut have been produced. These facts suggest the possibility of producing wheats that are resistant to rust, smut and root-rot. Considering the large annual losses caused by these diseases, it will certainly be worth while to make the attempt.

The rust problem demands co-operation between plant breeders and plant pathologists and generous support from the various provincial governments. In closing, I wish to make a concrete suggestion, namely, that the Western Canadian Society of Agronomy, through its president and secretary, endeavour to arrange a definite conference to be attended by the pathologists and plant breeders who are working on the wheat stem rust problem, and that this conference be held during the summer of 1922, preferably at University Farm, St. Paul, Minnesota, for it is there that the most work is being done both with rust forms and in the breeding of rust-resistant wheats.

Alfalfa Hybridization

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Introduction—In a former article (4)* dealing with the subject of hybridization of Alfalfa with Black Medick, the author explained the results of investigations which had been conducted in the seasons of 1911, '12, '13. During these years the field work was carried out at the Ontario Agricultural College, Guelph, and a part of the greenhouse work in the plant breeding department at the New York State College of Agriculture, Cornell University.

The investigations were continued at the Ontario Agricultural College until the autumn of 1915; since that time they have been continued at the Manitoba Agricultural College. Since the season of 1913 considerable work has been done with these hybrids; but new information accumulates very slowly, and it is purposed at a later date to issue a report of progress setting forth the outstanding results so far obtained.

The aim of the present paper is to give an explanation of the working methods adopted in these hybridization investigations.

Before launching directly into our subject, it will perhaps be advisable to draw attention to, and revise, certain statements made in the previous paper (4) to which reference has been made. The statements referred to are concerned with the natural fertilization of Alfalfa flowers (4; p. 449, col. 2) and are stated thus:

"From the results of our observations and tests, we may conclude: 'From the structure and mechanism of the Alfalfa flower, it is incapable of self-fertilization if it is not interfered with by external agencies, natural or artificial'."

The above statement was made on the result of a two years' test at Guelph. At that station, when flowers were caged so as to prevent access of insects, not a single seed

*The numbers in brackets in the text refer to the literature cited on the subject—a list will be found at the end of the paper.

was produced. In subsequent experiments we have found that when similar tests are conducted in Manitoba quite an appreciable amount of seed is obtained from flowers which have not been selfed artificially nor visited by bees.

The reasons for the striking difference between the results at Guelph and Manitoba are doubtless owing to the much dryer atmospheric conditions in Manitoba, together with higher temperatures and a greater amount of sunshine in summer than obtains in southern Ontario.

Fig. I. Alfalfa plant in full flower.

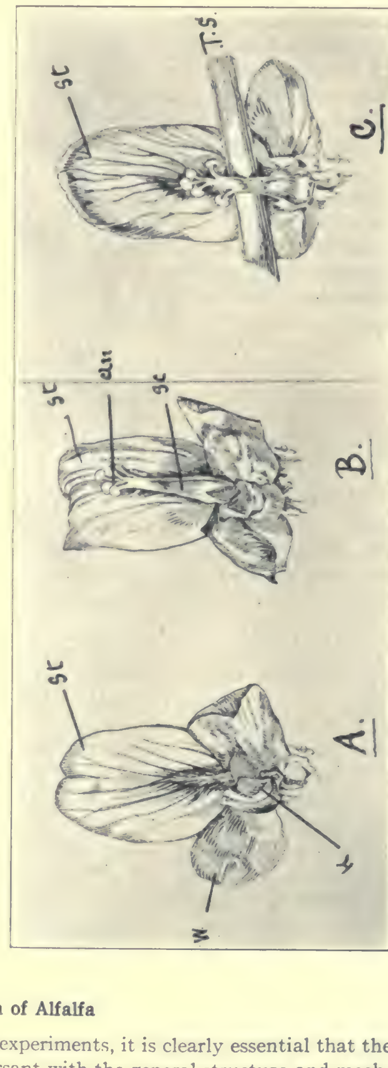

Fig. II. Alfalfa flower: front view (A, B, C).

Hybridization of Alfalfa

In conducting any kind of hybridization experiments, it is clearly essential that the worker should first become thoroughly conversant with the general structure and mech-

anism of the flowers of both parents he wishes to hybridize. This can best be obtained by carefully examining and studying the flowers as a whole; then carefully dissecting and examining each part separately.

Principal Parts of the Alfalfa Flower

(See Fig. II, Fig. III)

Calyx—The calyx is situated at the base of the flower; is greenish in color; and divided into five pointed sepals.

Corolla—The corolla arises from the inner portion of the calyx and is made of five petals.

1. One large and fairly upright petal known as the standard or banner. (st.)

2. Two smaller petals, one on each side of the standard, known as the wings. (w.)

3. Two inferior petals, somewhat loosely held together by the joining of their upper and lower edges, form a closed boat-shaped structure known as the keel. (k).

Stamens—There are ten stamens, the filaments of nine being fused together to form a hollow tube-like structure which may be termed the staminal tube. At the upper end of the tube the ends of the filaments are free, the anthers being attached to the free ends. The filament of the tenth stamen is quite detached and free from the other nine and is situated above the staminal tube. (s. c.)

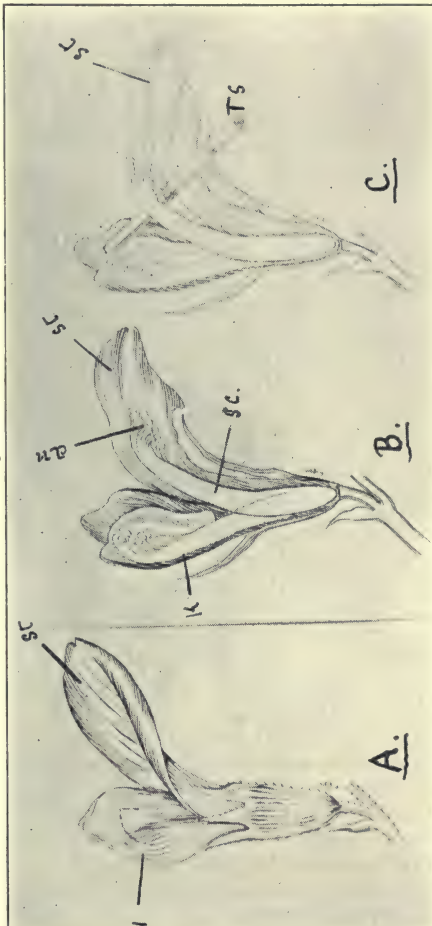

Fig. III. A—Alfalfa flower (side view).
B—Position of stamens before and after tripping.
C—Stamens in position for emasculation.

Pistil—The pistil consists of style and stigma and is contained in the staminal tube. The style being nearly equal in length to the tube, the stigma is brought into a position slightly below that of the anthers: this appears to favor the chances of the flower being self-pollinated.

The staminal tube together with the enclosed pistil may be conveniently referred to as the sexual column. This column is completely enclosed in the boat-shaped structure formed by the two keel petals and usually remains inprisoned in the keel until liberated

by wild bees or some other suitable external agency. This act of setting free the stamens and pistil is commonly known as tripping the flower.

Natural Tripping of the Alfalfa Flower

Tripping under natural conditions in the field is usually brought about by wild bees. Bees of the Megachile species seem to be most effective in tripping the flowers. The hairs on the legs and abdomen of these bees seem to be specially designed to catch and to hold the pollen, and these bees are frequently found with the under part of the abdomen and thorax as well as the upper parts of the legs completely loaded up with masses of pollen; thus it will be seen that this species of bee is a very useful agent in the distribution of pollen and in this way natural cross-pollination of the Alfalfa flowers is usually brought about.

Honey bees visit the flowers regularly in large numbers; but after extended obsevation over a number of years the writer has never yet seen a honey bee trip an Alfalfa flower in the open under natural conditions. This species of bee seems to visit the Alfalfa flower for the nectar alone and is able to extract this from the keel without displacement of the petals: moreover, the honey bee seems carefully to avoid tripping the flower.

Tripping the Alfalfa Flower by Hand

We do not purpose giving a detailed account of the mechanism of the Alfalfa flower, which causes tripping to take place. A detailed account by Piper will be found in (3: pp, 7-9). It will, however, be necessary to give a general account of the way the flower behaves under particular treatment.

If some small object, as a toothpick or the point of a lead pencil, is inserted between the upper edges of the keel petals, they are forced slightly apart, and the sexual column rises up with spring-like rapidity so that the stamens together with the stigma strike the standard with considerable force. The same result may be obtained by simply pressing down on the base of the keel with a pin or a piece of grass stem. When the apex of the sexual column rises up suddenly the staminal tube, acting like a released spring, curves upward and the anthers together with the stigma are brought against the face of the standard with considerable force.

The anthers being carried somewhat in advance of the stigma are first to strike the standard: this becomes dusted with the pollen from the bursting pollen sacs. The stigma, following immediately behind the anthers, is brought against the standard with considerable force, the impact being sufficiently strong as to cause the pollen grains to become firmly attached to the soft tissue of the stigma, thus rendering self-pollination of the flower practically certain.

At this stage, an interesting question arises as to whether the spring-like force exerted by the sexual column is due to the action of stamens or style. After repeated failures to solve this problem, a method of operating on the flower, which led to the solution of the difficulty was hit upon quite by accident.

The experiment may be carried out as follows: Select a mature, well-formed untripped flower. After tripping, carefully slit open the staminal tube, taking care not to injure the inclosed pistil. This operation may readily be performed by inserting the point of a dissecting needle into the base of the tube and working it carefully upwards to the top. After the slit has been made, the pistil will spring back very slightly, bringing the stigma away from the face of the standard; thus showing that it has been pushed into position and held there by the force exerted by the staminal tube in which it was inclosed.

Methods of Emasculation

In hybridization experiments, the method of emasculation generally practiced is that of selecting a flower in the bud stage, carefully removing the immature anthers before they have lost any pollen; then, when the stigma has assumed a moist, receptive condition, transferring suitable pollen to the stigma; finally, inclosing the flower in a paper bag or muslin bag until fertilization has taken place.

This method was tested on a large number of flowers, the work being done under varied weather conditions and at various periods of the day—morning, evening, and midday; but the results were far from satisfactory. Very few of the flowers that were operated upon produced seed. This want of success is, perhaps, not very surprising when all is considered.

An Alfalfa flower in the bud stage is very small and not easy to handle. It is also very soft and delicate and difficult to emasculate without causing such mutilation of the flower as will prevent fertilization taking place. Again at this stage of development, the stigma not being in a condition to receive the pollen, it is necessary to wait from one to two days after emasculation before pollination should be attempted. This means further handling of the flower and risk of further bruising or mutilation.

The second method of emasculation which was tested is the one originated and recommended by George W. Oliver, of the United States Department of Agriculture, Washington, D.C. (2). The main principles of this system have been followed in the present investigations with some slight modifications in details. The modified method may briefly be described as follows:

The flower selected to be operated upon should be fully open but quite fresh and in a healthy vigorous condition and not tripped. The operation consists in first tripping the flower so as to expose the sexual organs; then carefully removing the pollen, after which the stigma may at once be pollinated.

It has already been explained that during natural tripping of the flower, the sexual column is released from the keel, and the bursting anthers, together with the stigma, are forced against the face of the standard; thus ensuring self-pollination. Bearing this in mind, it is quite obvious that if we wish to practice cross-pollination, self pollination must be prevented. This may be brought about in the following manner: In tripping the flower, the operator, using a small toothpick, presses lightly on the upper surface of the keel at a point near the base: this pressure is sufficient to release the keel petals; thus to allow tripping to take place.

In performing this operation of tripping it is necessary to insert some object between the sexual column and standard which will effectually prevent the anthers and stigma from coming in contact with the standard. After testing various articles for this purpose, it was found that the flowering stems of well-ripened timothy cut into suitable lengths of about one inch served the purpose admirably. By taking one of these stems and using a firm, gentle pressure at the base of the keel, the sexual column is caused to trip gradually against the piece of timothy stem: this light object is easily held in a position just below the anthers and stigma; and it is sufficiently strong to prevent the anthers and stigma fron coming in contact with the standard (Fig. II B; Fig. III B.)

By means of a pocket lens it may now be observed that the anthers are closely packed around the stigma. Some may have burst and the stigma may be covered with pollen. The next operation is to remove the anthers and free pollen. This may be done by bringing a very fine jet of water to play upon the surface of the stigma and surrounding anthers and, by this means, both loose pollen grains and anthers are carried away very effectually. For this purpose a small hand-sprayer with rubber bulb and fine nozzle has been found very suitable.

The stigma should now be carefully examined with a lens to see if all pollen has been cleared away; then any drops of water adhering to any part of the flower should be re-

moved by the use of small strips of thin blotting paper. It was also found that the frayed edge of such paper is very useful for brushing away anthers or pollen grains which may not have been removed by the water spray. When a careful inspection of the stigma shows that is is quite clear and that all anthers and pollen grains have been removed, cross-pollination may be performed.

At this time, the stigma is still held in position by the piece of timothy stem and is standing quite free from the standard (See Fig. III C) so that little difficulty is experienced in pollinating the stigma. The pollen may be collected on the flattened end of a quill or a wooden toothpick and transferred directly to the prepared stigma of the female parent. The toothpick is preferred to a camel hair brush as it is more convenient to manipulate and can much more easily be cleaned or sterilized for future use.

A careful examination of the stigma should now be made to make certain that an abundance of healthy pollen is resting on the stigma (care should be taken to distinguish between pollen grains and empty anther sacs). If found satisfactory, the piece of timothy stem may be removed. In doing this, see that it is removed at right angles to the sexual column and in such a way as not to displace the stigma or the adhering pollen. The removal of this piece of timothy stem allows the process of tripping to continue until it is completed. The pollen-covered stigma then presses forward and comes in close contact with the standard; thus, the pollen grains are entrapped and become firmly attached to the face of the stigma, thus completing the operation.

After pollination, the flower is marked by tying a piece of thread loosely around the pedicel. In addition, a small tag is attached to the base of the stem of the flower cluster. On the tag is recorded the parents used in making the cross, and the date. The particulars as to male and female parents, condition of weather, date, and other essential information is recorded on field record sheets with special headings for this purpose. The flower should now be inclosed in a suitable manner so as to protect it from the visits of insects and to lessen the risk of introducing pollen from any outside source.

After testing paper bags which did not prove to be very suitable as they were easily broken or displaced during wind storms, cages sufficiently large to inclose a whole plant were used. (Fig. IV).

Fig. IV. Method of protecting individual plants. Clover species in foreground: Alfalfa in background.

These cages were made of ordinary wire netting—two inch mesh—and covered with cheese cloth: in size, they were about two and a half to three feet high and about eighteen inches in diameter and held in position over the plant by means of wooden stakes. It was found, however, that the cheese cloth being somewhat close in texture, it was necessary to remove the cage directly after fertilization had taken place; otherwise the plant suffered from being too closely confined. In later experiments, mosquito muslin and tarlatan were substituted for cheese cloth with beneficial results. This method of

protecting, emasculating, and pollinating, was practiced on a large number of flowers and gave very satisfactory results. (Fig. V).

By using control tests it was found that flowers emasculated as described above and not pollinated generally proved to be quite sterile; but, when pollinated, a fair percentage produced well-developed seed pods.

In the seasons from 1912 to 1917 a method of clearing away pollen was tested, which gave very satisfactory results. Instead of using a fine jet of water for this purpose the anthers and any pollen grains adhering to the surface of the stigma were brushed away by using the frayed end of a piece of gardener's raffia: this improvised brush was found to be very effective and moreover very convenient; as after each operation, the end of the raffia may be clipped off, thus a fresh, clean brush is available for each operation.

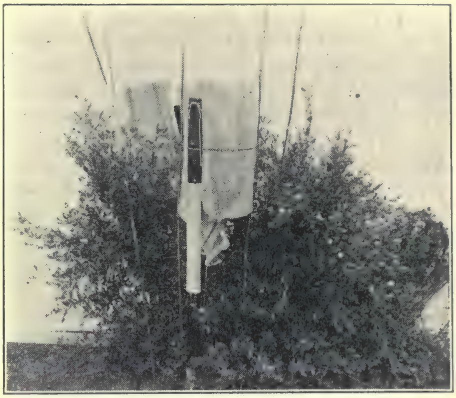

Fig. V. Method of protecting a single branch of a plant. As the plant grows, the muslin-covered cage can be adjusted to any part of the supporting stake.

Reliability of Method of Emasculation Tested

During the course of these investigations many experiments have been made to test the reliability of the methods of emasculation described above. In one series of tests, out of 189 flowers emasculated, four pods were produced; but only one viable seed. In another series, 66 emasculated flowers produced ten pods which contained no fully developed seeds.

It was found, however, that under suitable conditions where flowers were carefully emasculated and pollinated a fair percentage of fertile crosses was obtained: if conditions were unfavorable, few or no fertile crosses were obtained. An average result may be taken at about forty to fifty per cent fertile.

Conditions Favorable for Cross-Fertilization

The successful cross-fertilization of Alfalfa depends on several factors which are very difficult to control; hence, it is readily seen that it is impossible to standardize either conditions or methods of working: this is especially evident when the work is being carried on under natural conditions in the field.

I. Weather Conditions—As would naturally be expected, the state of the weather affects the work very materially not only on the day pollinations are made but also for at least twenty-four hours previous, and for a similar period after the work has been done.

Our results show that almost invariably the greatest percentage of fertile crosses have been obtained during a continuous period of fine weather, moderately warm and without rain.

II. Condition of the Plants—There should be sufficient moisture and plant food in the soil to supply the immediate needs of the plant without forcing a too luxuriant growth. A steady and healthy growth is very desirable: too much moisture together with a highly manured soil tends to overproduction of stem and leaf, which is detrimental to seed formation. On the other hand, with an insufficient supply of moisture, many of the flowers wither and fall off before fertilization takes place.

Condition of the Pollen—The pollen should be fully mature; and yet not too old. A good indication as to the proper condition of Alfalfa pollen is obtained by carefully observing the flowers as they are being tripped by hand. During the process of tripping when the anthers burst and the pollen is seen scattered in the form of a fine dust, we have an indication that the pollen is in a good, healthy condition.

To make an exact determination of the viability and vigor of the pollen, it is necessary to make carefully controlled laboratory tests.

Condition of the Stigma—When in the right condition to receive the pollen, the stigma has a well-rounded surface and has a somewhat shiny appearance. This condition is usually seen as soon as the flower is fully opened. In choosing flowers for the female parent our usual practice has been to select flowers somewhat immature rather than old flowers. Experiments are under way with the object of trying to determine in what stage the flowers are in the best condition to receive the pollen.

Best Time of Day for Crossing Plants—Judging from crossings done at various times in the day (ranging from early morning throughout the day and in the evening) we have no clear indication that the success or failure at one time of the day is greatly different from that of another. The condition of the operator seems to have more effect on the results than the time of day and, other things being equal, the work which is done at a time of day congenial to the worker seems to give the best results.

After Pollination—The flowers may be suitably protected by muslin cages in the manner described above. When fertilization has taken place. the protection should be removed so as to give the plant a full measure of air and sunlight, which together aid in the development of plump, healthy, well-grown seed.

The condition of the seed pods should be examined from time to time throughout the summer and when thoroughly ripe should be carefully collected, counted, and a full record made on the sheets prepared for this purpose. The coin envelopes in which seeds are collected should also be clearly marked, showing contents; then the seeds may be stored in a dry and moderately warm place away from mice or other vermin.

Raising Plants from Hybrid Seed

The system adopted in these experiments is as follows: The seed is germinated in water in open earthenware dishes and, as the seeds sprout, they are picked off and planted in rows in clean soil previously prepared in suitable pans or flat boxes. In a sample of well-ripened Alfalfa seed, we always find a percentage of hard seeds which do not germinate readily: these will be left behind in the germinating dish. If these hard seeds are properly treated with sulphuric acid so as to soften the seed coat, a rapid germination may usually be obtained.

Method of Hastening Germination of Hard Seeds

Apparatus required—

1. 1 dozen clean, dry test tubes.
2. Commercial sulphuric acid.
3. Glass stirring rods.
4. Fine strainer (a coffee strainer is suitable for small lots).
5. A good supply of running water from a tap; also, large pail of water.

Method of Working—1. Place the hard seeds in a dry test tube; then add sufficient acid to immerse the seeds thoroughly. The seeds will float in the acid, and the mixture should be stirred frequently so as to get all seeds thoroughly saturated. Allow the acid to remain on the seeds for about fifteen to twenty minutes, stirring frequently.

2. *Pour the acid with seeds into strainer*; then dip strainer into a pail or large basin of water so that the seeds are completely immersed. Stir the seeds in water whilst they

are in the strainer: this is to wash the seeds free from acid. Any traces of acid may be washed away by holding strainer and seeds under running water from the tap.

The seeds may now be spread out on a plate to dry: a little powdered quicklime dusted on the seeds will hasten the drying, also neutralize any acid which may not have been completely removed in the washing process. These seeds may now be germinated in the ordinary way.

With very hard seeds it sometimes takes two or more treatments with acid before they are induced to germinate.

In re-treating the seeds before adding the acid, be sure to dry the seeds thoroughly; then repeat the operations as outlined for the first treatment. By repeated treatments, the hardest seeds can usually be induced to germinate and made to produce healthy plants.

Caution—The above method should be carried out strictly in accordance with instructions given. By improper manipulation, the germinating power of the hard seed may be completely destroyed.

Hardening of Seedling Plants

After germination of the seed and when the seedling plants have got to about the fourth leaf stage, they are transplanted singly into three-inch flower pots. With a moderate greenhouse temperature, a sturdy growth is encouraged, and finally the plants are transferred to a cold frame to harden off before planting out in the open field.

The germination of the seeds and the manipulation of the plants are so adjusted that plants are usually ready to transplant out in the field from about the middle to the end of May. In the field, the plants are usually spaced from three to four feet apart each way. This allows for the study of the individual plants and also gives the necessary working space between the plants. (Fig. VI).

Fig. VI. Second growth of Alfalfa, showing method of spacing plants.
(Note—The plants selected for seed have not been cut.)

If Alfalfa plants are raised in the manner described above, it is usually possible to obtain seeds the same year of planting and thus the worker is enabled to continue further investigations with a minimum of lost time.

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A Comparison of Some Physical Properties of Immaturely Frosted and Non-Frosted Seeds of Wheat and Oats

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Introduction

Grain growing in the Canadian prairies and the northern states of the Union is annually subject to the serious hazard of frost injury. Not only are yields reduced and the quality depreciated from the standpoint of the farmer by early fall frosts, but frost-injured grains are discriminated against in those industries which engage in the manufacture of cereal products.

Frosted grains are those which have been injured by frosts occurring during the developing or maturing period, that is, the months of August and September. The extent of the injury varies greatly with different years, and frosts are generally more prevalent in some districts than in others. Some localities are practically free from injurious frosts, while others are very rarely entirely free. It is probably safe to say that every year there is more or less extensive injury from frosts to our Canadian prairie-grown grains. In the Dominion Seed Laboratories at Calgary and Winnipeg, from ten to fifteen thousand samples of oats are tested for germination annually, and it has been estimated that at least 20 per cent of the samples of oats tested are found to be unsuitable for seed purposes on account of supposed frost injury.

Most of our modern grain experts have some general knowledge of the symptoms of frost injury in grains, particularly wheat, but it is doubtful if many are able to distinguish with certainty between frost symptoms and effects which have been produced by other unfavorable conditions. Our present knowledge of this question appears to be based largely on general observation, rather than on definite and reliable data. If agriculturists, manufacturers and inspectors are to be able to identify the effects of frost and to appreciate its significance in connection with the various cereal grains, much more precise and intensive study must be given this matter than has heretofore been done. From a purely scientific standpoint it is essential that investigation into the nature of frost injury to maturing seeds be undertaken. Much information has been acquired relating to the phenomena accompanying or resulting from the freezing process in vegetative organs of plants, but, so far as the writer is aware, very little effort has been made to study the precise effects of freezing on immature seeds, either as regards the gross changes brought about or the protoplasmic disturbances occasioned.

Problem

With a view to obtaining information as to the precise effects of premature freezing of seeds, the writer has undertaken a course of investigation which it is hoped will ultimately result in the acquisition of fundamental knowledge, useful both scientifically and economically.

Historical

Very few investigators, apparently, have given attention to the effects of freezing temperatures on immature grains. Bolley in 1893 described the appearance of frosted wheat as follows: "Frosted wheat may have a greenish or bronzed appearance which is due to some chemical change brought about in the content of the cells of the seed coat, which because of immaturity have not yet transferred all their food material to the body of the grain. In those cases where the frost had been severe enough to cause the bronzing and darkening effect on the grain some cells of the more delicate parts of the root and body of the embryo are found to be killed, showing the characteristic result of frozen cells." In 1904 Bolley further says: "By carefully softening and sectioning the grains I was able to make careful microscopic tests of the contents. I found that the characteristic wrinkling of the surface of the grains was due to the effect of frost upon the pericarp, but that there was no apparent change of effect upon any of the inner layers or contents of the grain."

Kiesselbach and Ratcliff in 1918 studied the effects of frosts on maturing corn (maize). They found that severe freezing of immature or moist corn causes the embryo to change from a normally light or creamy color to a dark or yellowish-brown color. This change was usually accompanied by a lowering of vitality, and it would indicate that a chemical change had taken place.

Method

Our problem has been divided into three phases, which are being investigated in the following order:

1. Changes of physical properties of seeds due to freezing.
2. Chemical peculiarities brought about in seeds by freezing.
3. Physiological features of frosted seeds as compared with those of non-frosted seeds.

It seemed advisable that gross features, such as the physical properties, should be studied first, as from such a study suggestive leads for chemical and physiological investigations might be obtained. Moreover, a thorough knowledge of the physical properties of frosted seeds might also have an important economic bearing in connection with grain inspection. Consequently, this phase of the work was entered upon during the past summer. The frosted and non-frosted seeds are being studied much as a mineralogist might examine minerals or crystals. An attempt is being made to measure such properties as dimensions, volume, density, weight per 1000 kernels, percentage of moisture content, general appearance, hardness, and absorptive capacity for water and salt solutions, and to compare these measurements for normal and frosted seeds. In this investigation we are utilizing material obtained both through artificial freezing in the laboratory or cold storage plants and through freezing under natural conditions in the field. Due to lack of equipment, very little has as yet been done to secure artificially frozen material, but some material has been obtained which was frosted in the field under close observation as to stages of maturity, degrees of freezing and other climatic influences prevailing at the time of freezing.

As general observation has indicated, the extent of injury from any frost which is not too severe depends largely on the stage of maturity of the crop. The less mature

the grain, the more severe is the injury. With this in mind, it seemed desirable to secure material frosted at different stages of maturity, and for this purpose series of plots were seeded in the late spring of 1921, at intervals of ten days, with the hope that when a frost occurred in the late summer, plots of the same kind of grain would be in different stages of maturity. In order that the extent and duration of freezing temperatures might be recorded, a minimum thermometer and a thermograph were kept among the plots in the field. Other climatic conditions, including rainfall, sunshine, evaporation, relative humidity of the atmosphere, etc., were also recorded daily throughout the maturing season, as it was thought some of these factors might be required to explain peculiarities of the grain. To compare frosted samples with non-frosted ones, a series of samples was collected, three samples per week from each plot, commencing as soon as the grain reached the late milk stage. In this way it was possible to obtain from each plot a sample just before and one shortly after any frost that might occur. In taking these samples the spikes or panicles, as the case might be, were cut off from the straw, after which they were placed in a building to air-dry, where they were not subject to frosts or wet weather. After drying thoroughly they were tested for germination, the germination result being regarded as a criterion of the extent of frost injury. Such a criterion is not entirely satisfactory, since very probably seeds may be considerably injured by freezing without being devitalized, but it is the most satisfactory one that could be utilized in the early stages of this investigation.

Results

The data here included are from preliminary work, and therefore inconclusive. Much further testing must be conducted before final deductions can be made with respect to the physical properties here mentioned. However, the data so far obtained may be of interest and may tend to stimulate further investigation of this question.

Dimensions

The question often arises, "Does freezing affect the size of kernels of grain? Do kernels shrink after immature freezing?" Data in this connection were obtained in an examination of samples of oats taken from field plots grown in 1921 at the University of Alberta. Samples designated 9 in Table I were taken just before the first frost, except for 2 degrees F. occurring about a week previously, which did no appreciable injury so far as could be observed. Samples bearing this designation are therefore considered as non-frosted. Samples designated 10 were subject to 8.5° F. of frost and those designated 11, to 8.5° F., followed by 13° and 2° F. The samples referred to in Table I were measured as to width and thickness with a delicate micrometer. One hundred primary kernels were taken indiscriminately from each sample for this purpose. The length of the kernels was not determined as this was found to be impracticable, largely on account of the hairiness of the apex of the kernel.

	Sample C9	Sample C10	Sample C11
Date harvested	Sept. 8	Sept. 10	Sept. 13
Stage of maturity (oats)	Dough	Late dough	Late dough
Frost exposures	None	8.5° F.	8.5° F., 13.0° F., and 2.0° F.
Germination (oats)—			
Preliminary	89%	18%	17%
Final	97%	81%	61%

TABLE I

Oats—Size Statistics (Primary kernels only used)

	Width in mm.			Thickness in mm.			Width by Thickness		
Samples	C9	C10	C11	C9	C10	C11	C9	C10	C11
Average	2.33	2.34	2.31	1.80	1.80	1.79	4.194	4.212	4.135
Medium	2.35	2.36	2.33	1.80	1.81	1.80	4.230	4.272	4.194
Mode	2.35 to 2.36	2.39 to 2.41	2.44 to 2.48	1.64 to 1.65	1.84	1.86 to 1.89	....	....	....
Standard deviation	.159	.165	.177	.168	.165	.182	....	....	....

The dimensions of C9 (non-frosted) and of C11 (frosted) differ very little. These are slightly greater for C9, as indicated by the greater averages and medians. The width multiplied by the thickness magnifies this difference somewhat. On the other hand the mode, *i.e.*, the measurements applying to the greatest number of individuals in the sample, is less for C9 than for C11, both in the case of width and thickness. The standard deviation (average deviation from the average) is greater for C11 for both width and thickness. This indicates a greater variation in the dimensions for seeds of C11 than for those of C9. In other words, the size of the frozen seed is less uniform than that of normal seed. No size determinations were made in the case of wheat on account of the pronounced irregularity in the shape of the kernels, this irregularity having been caused by shrinkage due to the immature condition of the kernels at the time of harvesting.

Volume and Density

Volume and density determinations were made for non-frosted and frosted samples of both oats and wheat. Five hundred kernels were used for each determination in duplicate. In the case of oats the naked cariopses were used. It seemed impracticable to make volumetric determinations by the liquid displacement method on account of the difficulty of getting a liquid which would not be absorbed by the seeds, and of preventing air bubbles being carried into the liquid in the creases or among the hairs on the grains. Consequently, a displacement of gas (air) method was used. A modified volumenometer was used for this purpose. Having the weight of 500 representative kernels and having obtained the volume in cubic centimetres by means of the instrument just mentioned, the density was calculated by dividing the weight in grams by the volume in cubic centimetres. Table II gives data with respect to these measurements.

TABLE II

Showing Results of Volumetric and Density Determinations for Non-frosted and Frosted Oats and Wheat.

Sample	Stage of Maturity	Condition	Average Weight of 500 Kernels in grams.	Average Volume Cc.	Average Density
Oats C9 (cariopses)	Dough	Non-frosted	11.889	8.356	1.42
Oats C11 (cariopses)	Late dough	Frosted	11.252	7.913	1.42
Wheat C9	Green—turning yellow	Non-frosted	13.284	8.800	1.50
Wheat C11	Pale yellow	Frosted	13.375	8.945	1.49
Wheat D9	Green white	Non-frosted	8.548	5.672	1.50
Wheat D11	Light Green	Frosted	8.228	6.523	1.41

In Table II it will be noted that the volume of 500 kernels of oats is greater for C9 (non-frosted) than for C11 (frosted). The weight is also greater for C9, but the density for the two is the same. This would suggest that the volume of oats diminishes somewhat as a result of freezing. C11, not being harvested until five days later than C9, had this additional period to continue its growth. With the wheat the case seems to be reversed, *i.e.*, C11 (frosted seeds) have a greater volume and greater weight per 500 kernels than C9 (non-frosted seeds). This would suggest that wheat at this stage of maturity continues to increase in size, even after exposure to 13° F. of frost.

Weight Per 1000 Kernels

Weight per 1000 kernels determinations were made in duplicate and the averages are inserted in Table III. In the case of oats, the naked cariopses were used.

TABLE III

Weight Per 1000 Kernels and Percentage Moisture for Non-frosted and Frosted Oats and Wheat

Samples	(1) Stage of Maturity	Frost Exposures	Weight per 1000 Kernels	Percentage Moisture After Air Drying
Oats C9	Dough	Non-frosted	23.778	....
Oats C10	Late dough	8.5°	20.277	....
Oats C11	Late dough	8.5° and 13° F	23.903	....
Wheat B9	Yellow	Non-frosted	33.653	9.02
Wheat B10	Yellow shrinking	8.5°	34.697	8.97
Wheat B11	Yellow shrinking	8.5° and 13° F	34.330	8.68
Wheat C9	Green	Non-frosted	26.568	10.09
Wheat C10	Yellow-green	8.5°	25.909	8.20
Wheat C11	Pale yellow	8.5° and 13° F	26.581	8.09
Wheat C13	Pale yellow	8.5° and 13° F	27.019	....
Wheat D9	Greenish white	Non-frosted	17.821	7.53
Wheat D10	Green	8.5°	18.002	7.73
Wheat D11	Light green	8.5° and 13° F	18.109	7.93

The results in connection with these determinations are somewhat variable and therefore inconclusive. There was some evidence, however, that wheat exposed to 13° F. of frost at the pale yellow stage of maturity continued to increase in weight when allowed to grow further after this frost.

Percentage of Moisture Content

Table III gives also the results of percentage moisture tests for the samples as indicated. It was thought that freezing might affect the immature kernels in such a way as to make them, when drying out, give up their moisture to the atmosphere to a greater extent than would be the case with non-frosted kernels. This suspicion was suggested by the observation of a somewhat greater degree of brittleness in frosted samples, which will be referred to later. The results tabulated in Table III would support this suspicion to a certain extent in the case of wheat fairly advanced in maturity, but for quite immature wheat the reverse seems to be the case. This point in connection with oats has not yet been studied.

(1) Owing to the indefiniteness of such terms as milk, dough, etc., for referring to stages of maturity of wheat, we have adopted the terms white, green, green-yellow, pale yellow, yellow, yellow-shrinking and amber, which refer chiefly to the color of the cariopses.

General Appearances

Such general features as color, lustre, surface, fracture, tenacity and character of outer layers of the seed coat have been compared in frosted and non-frosted wheat. For the Marquis variety, which we have used in all our tests, a comparison of these features may be tabulated as in Table IV.

TABLE IV

Appearances of Non-frosted and Frosted Wheat

	Non-frosted	Frosted
Color	Amber	Amber to bronze to greenish
Lustre	Satiny smooth	Dull satiny
Surface	Smooth and regular	Wrinkled at right angles to long axis of kernel.
Fracture	Sugary	Sugary, similar to normal
Tenacity	Slightly sectile	Less sectile and more brittle
Outer layers of seed coat	Firmly attached	Bulged in transverse wrinkles and tends to peel.

The most apparent features distinguishing frosted and non-frosted wheat are those of color and nature of the surface layers of the coat. As Bolley pointed out, freezing tends to produce a bronze or greenish color. This seems quite likely to occur if maturity is not too far advanced. A fairly severe frost is also seemingly necessary to produce this discoloration. In the case of quite immature seed some of the kernels may turn quite green as a result of frost. It seems to be uncertain as to what is the nature of this discoloration. In normal ripening or even when harvested immaturely and allowed to dry out slowly, the chlorophyll breaks down and the kernel takes on its ordinary mature color; but if severe frost occurs when the kernels are quite immature the chlorophyll apparently only partially breaks down. Moreover, the coloring matter which gives wheat its yellow color fails to develop. Frost, therefore, seems to inhibit the process by which the normal coloring matter is produced. The transverse wrinkling of the surface of the seed is a point of interest. These wrinkles are little bulges or blisters of the outer layer or layers of the seed coat. They are apparently caused by the local separation of the outer coats from the inner. This separation may possibly be brought about by the formation of ice in the inter-cellular spaces of the seed coat. When the kernel further matures after freezing, it loses moisture and contracts, with the result that the outer coating at the areas of separation does not adhere to the underlying tissues but bulges outward, forming the characteristic folds. In the case of severe freezing of very immature wheat, this blistering does not occur to anything like the same extent. In fact, it does not usually occur at all.

Hardness

By the term "hardness," as applied to grains, is understood that property of the kernel which enables it to withstand an impact tending to crush it. Different samples show considerable differences in hardness, but it is a very difficult matter to actually assign in terms of standard units, values for differences in this property of hardness. The writer is only attempting to make comparative determinations between such types of grain, in order to get some notion as to the effect of freezing on hardness. With this object in view an impact device has been made by which a weight falls from various heights on to a kernel placed on a small anvil. The intensity of the impact varies with the height from which the weight falls and the lowest height from which it must fall to crush the kernel is registered for that particular kernel. By thus testing 100 representative kernels of a sample, one gets a distribution of height values, ranging from 2

to 12 inches. By comparing the distribution of the 100 kernels among these values, one may compare one sample with another with respect to hardness. Our result would indicate in general that for wheat less forceful impacts are required to break frosted than non-frosted kernels, with the exception of a very few kernels well advanced in maturity at the time of frost, where frosting appears greatly to increase the hardness. The seeming diminution of hardness under impact tests for frosted kernels is probably due to the increased brittleness occasioned by the freezing process.

Absorption

The question arose as to whether freezing might not alter the water relations of seeds in such a way that frosted and non-frosted seeds would take up water or solutions at different rates and to different extents. A. P. Brown (in "Annals of Botany," Vol. 21) found that the integument of cereal grains functions as a semi-permeable membrane. It was thought that freezing might destroy this semi-permeability. On the other hand, the absorptive capacity of the seed contents—Starch, protein, etc.,—might be changed by freezing. In order to examine this property of absorptibility, a number of tests were made where air-dried weights of frosted and non-frosted seeds of wheat and oats were soaked 6 to 8 days in distilled water, 2 per cent NaCl, 8 per cent NaCl, and 32 per cent (conc.) NaCl solutions. These tests in duplicate were kept in a refrigerator at a temperature on 8 to 10 degrees C. in order to reduce as much as possible any physiological activities which might be induced by the inhibition of water. The seeds were drained, washed, dried with filter paper and weighed at intervals, after which the absorption represented by percentage increase in weight, was calculated for each sample. Tables V, VI and VII (see also graphs) give results for these tests in terms of average percentage of increase of weight, based on the original air-dried weights of the seed.

TABLE V

Wheat at the Green-yellow Stage. Absorption from Distilled Water and Solutions of Sodium chloride by Air-dried Wheat, Non-frosted and Frosted at the Green to Yellow Stage of Maturity. Each Number is the Average of Results for Two Tests.

Hours Soaking	Distilled H_2O C9 (Non-frosted) Percent	Distilled H_2O C11 (Frosted) Percent	2 Percent NaCl C9 (Non-frosted) Percent	2 Percent NaCl C11 (Frosted) Percent	8 Percent NaCl C9 (Non-frosted) Percent	8 Percent NaCl C11 (Frosted) Percent	32 Percent NaCl C9 (Non-frosted) Percent	32 Percent NaCl C11 (Frosted) Percent
2	22.6	29.2	20.0	27.9	17.2	23.8	12.6	20.2
6	33.1	38.9	31.8	36.7	24.0	30.5	15.9	22.4
10	42.7	48.8	40.1	46.6	31.0	38.9	19.8	27.1
24	49.5	59.3	49.9	56.9	38.0	48.1	28.2	34.8
48	59.4	67.0	58.1	64.0	51.0	59.1	38.3	45.7
72	69.4	74.9	61.9	70.3	47.3	58.7	32.0	42.2
96	75.5	79.8	61.8	72.2	46.6	59.8	32.5	41.8
120	76.7	82.6	59.9	71.0	44.0	58.8	30.6	41.6
144	81.1	83.9	61.2	73.4	45.5	60.0	30.9	41.6

TABLE VI

Wheat at the Green Stage. Absorption from Distilled Water and Sodium Chloride Solutions by Air-Dried Wheat, Non-frosted and Frosted, at the White to Green Stage of Maturity. Each Number is the Average of Results for Two Tests.

Hours Soaking	Distilled H_2O D9 (Non-frosted) Percent	Distilled H_2O D11 (Frosted) Percent	2 Percent NaCl D9 (Non-frosted) Percent	2 Percent NaCl D11 (Frosted) Percent	8 Percent NaCl D9 (Non-frosted) Percent	8 Percent NaCl D11 (Frosted) Percent	32 Percent NaCl D9 (Non-frosted) Percent	32 Percent NaCl D11 (Frosted) Percent
2	21.1	28.8	24.4	27.0	21.2	26.1	17.3	20.6
6	36.8	44.4	38.6	45.3	31.8	37.5	21.2	25.4
10	47.0	58.0	47.1	56.0	38.2	45.5	24.6	29.9
24	60.2	77.5	58.2	71.7	44.5	55.8	28.7	35.1
48	73.0	97.1	63.4	85.4	46.7	67.2	30.4	39.8
72	81.4	107.5	65.9	105.9	49.0	100.4	33.5	63.3
96	90.8	120.5	72.4	109.9	53.8	91.5	36.7	55.8
120	94.7	128.0	70.5	112.6	56.3	92.5	37.8	58.6
144	94.3	127.8	66.2	112.4	52.0	92.8	35.8	57.5
168	98.7	130.9	69.8	116.1	55.6	97.5	37.1	60.3

TABLE VII

Oats at the Dough Stage. Absorption from Distilled Water and Sodium Chloride Solutions by Air-dried Oats, Non-frosted and Frosted, at the Dough Stage. Each Number is the average of Results for Two Tests.

Hours Soaking	Distilled H_2O C9 (Non-frosted) Percent	Distilled H_2O C11 (Frosted) Percent	2 Percent NaCl C9 (Non-frosted) Percent	2 Percent NaCl C11 (Frosted) Percent	8 Percent NaCl C9 (Non-frosted) Percent	8 Percent NaCl C11 (Frosted) Percent	32 Percent NaCl C9 (Non-frosted) Percent	32 Percent NaCl C11 (Frosted) Percent
2	22.1	21.0	17.9	17.2	15.1	15.9	9.5	9.1
6	29.1	34.0	27.9	25.5	20.6	22.0	10.1	10.5
10	38.5	42.2	32.4	33.6	25.4	26.6	13.0	13.6
24	47.6	47.9	40.5	42.5	31.2	32.3	16.5	17.8
48	59.3	62.3	44.7	50.7	36.1	41.4	22.4	22.7
72	66.5	67.1	52.8	56.5	39.8	43.3	24.8	23.9
96	65.3	70.3	50.9	56.3	39.0	44.8	23.3	24.9
120	69.5	76.6	52.3	57.6	41.2	48.5	25.1	26.3
144	73.5	77.1	58.3	60.8	43.7	53.5	27.1	27.9
168	67.7	80.3	58.2	60.2	46.1	56.8	27.5	29.9
192	76.7	84.8	59.5	64.5	50.3	60.6	29.8	33.8

In these tables it is apparent that the amount and rate of absorption were least for the concentrated solution, and that these increased progressively from a minimum at highest concentration to a maxium for distilled water. This applies both to non-frosted and frosted seeds.

The gradation of absorption in the cases of the frosted seeds for solutions of diminishing strength would suggest that the semi-permeability of the integument

was not destroyed, although one cannot definitely draw that conclusion, as even though the semi-permeability were completely destroyed the salt penetrating the interior of the kernels would probably affect the absorptiveness of the colloids in such a way that the more concentrated solutions would be absorbed to a less extent than would the dilute solutions.

The absorption for frosted seeds is in all cases considerably greater than for non-frosted seeds. This shows that freezing increased the absorptive capacity of both the wheat and oats.

It seems reasonable to suppose that the increased absorption in the case of the frosted seeds may be due to their greater sugar content. At the time when frost occurred the physiological process by which sugar was being changed to starch was suddenly stopped by the frost leaving a certain amount of sugar in the seeds. In the case of non-frosted seeds which were harvested before the frost this process was able to continue until all the sugar had been entirely condensed to starch. Hence the probable occurrence of more sugar in the frosted seeds than in the non-frosted ones. This greater prevalence of sugar may possibly explain the greater absorptiveness by osmosis through the integument of the seed, which the frosted seeds displayed.

There is also a greater difference in absorption between non-frosted and frosted seeds of very immature wheat (D9 and D11) than between the non-frosted and frosted seeds of wheat at a more advanced stage of maturity (C9 and C11). This would indicate that the absorptive capacity of very immature wheat was increased by freezing at the early stage more than by freezing at a later stage. This suggests that the less mature the wheat the greater is the effect of freezing. Here is a conclusion that corresponds to general observations with respect to the effect of freezing on germinability of wheat exposed to freezing temperatures at different stages of maturity.

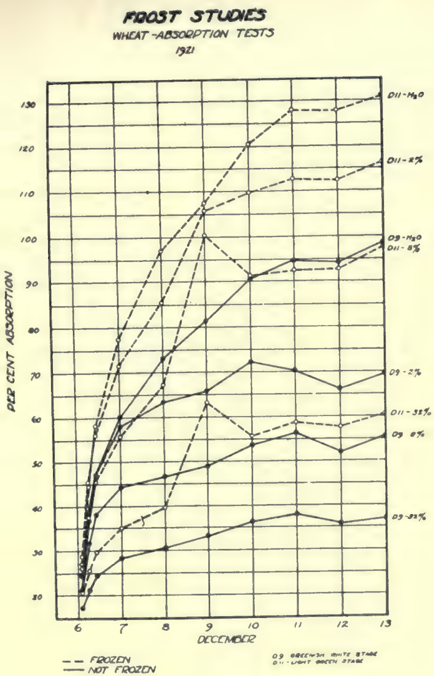
In graphs 1 and 2, it will be noticed that in curves C9—32 percent, C9—8 per cent and C11—32 percent graph 1, and in curves D11—32 percent and D11—8 per cent, graph 2, there are decided elevations for December 9, followed by declines for December 10. These irregularities may be explained as follows: Our solutions became exhausted on December 8, and in making up new lots a mistake occurred by making the solutions only 1-10 as strong as they should have been. In consequence of these weaker solutions, the absorption, as indicated by weighings made on December 9, had greatly increased. The mistake was discovered on December 9, and new solutions were made up of the correct concentrations, with the result that on December 10 these particular lots of seeds showed considerable losses due to the withdrawal of solution previously absorbed, this withdrawal being brought about by the greater osmotic pressure of the stronger solutions.

More work in connection with this question of absorption in frosted seeds is being planned and will be reported on later.

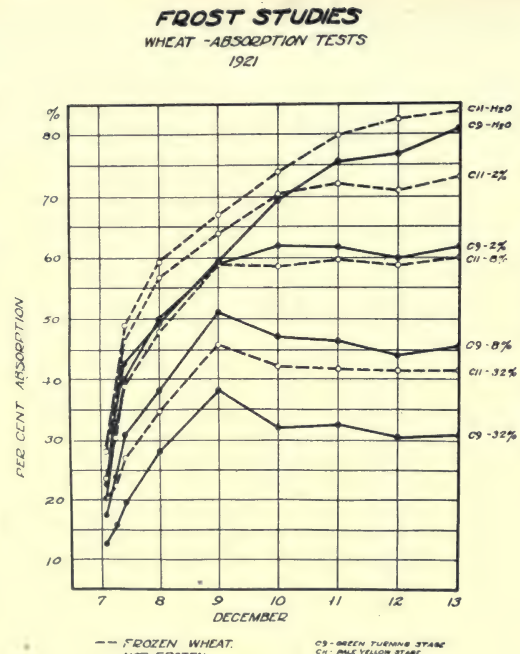
Conclusion

This paper must not be thought of as a conclusive report on our investigation in connection with any of the physical properties of frosted grain. The tests have been purely preliminary in character, and will have to be repeated and extended with other material before reliable conclusions can be drawn. The results thus far obtained, however, may be interpreted as pointing to the following probable conclusions:

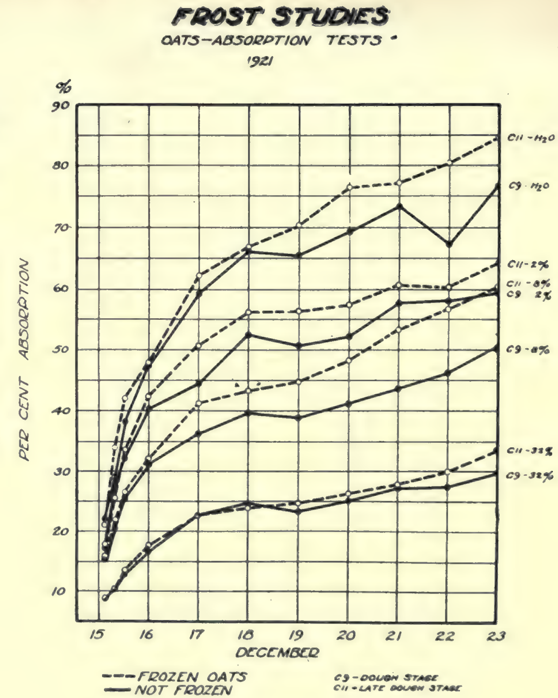
1. Frosting oats at the dough stage to the extent of 13° F. probably causes a slight shrinkage in the size of the cariopses. In the case of wheat subject to the same freezing, the data do not indicate any shrinkage. In fact, there is some evidence that the wheat kernel continues to develop after 13° F. frost at the yellow stage, if left intact with the plant.



Graph I—Very immature wheat.
D9 Non-frosted; D11 Frosted.



Graph II—Immature wheat.
C9 Non-frosted; C11 Frosted.



Graph III—Immature oats.
C9 Non-frosted; C11 Frosted.

Absorption of solutions of sodium chloride and distilled water by frosted and non-frosted immature wheat and oats.

2. The volume of oat kernels is probably reduced by freezing, although the density is not altered, but the volume of wheat kernels seems to continue to increase if left to grow. The density of the kernels of oats and wheat does not seem to change appreciably by freezing except in the case of very immature wheat when it is reduced.

3. The results of weight per 1000 kernels tests are variable, and therefore inconclusive. It would seem, however, that wheat frosted by 13° F. at the pale yellow stage of maturity continues to gain in weight if permitted to stand in the field.

4. Frosted wheat exposed to ordinary atmospheric conditions seems not to be quite so retentive of its moisture as non-frosted wheat.

5. In general appearance frosted wheat as compared with non-frosted wheat has (*a*) a more variable color, from light amber to bronze or green, (*b*) duller lustre, (*c*) transversely wrinkled surface, (*d*) slightly higher degree of brittleness of endosperm, (*e*) less closely attached outer layers of the seed coat. In the case of oats, frosting tends to fix the greenish color, particularly at the germ end, if the oats are quite immature; it increases the brittleness and frequently darkens the interior of the endosperm as well as the strand of tissue which traverses the bottom of the groove.

6. By "hardness" is meant the degree of resistance which the kernels exhibit when subject to impacts of varying intensity. Wheat which has been frosted appears to suffer thereby a diminution in hardness. This may have some relation to its slightly increased brittleness.

7. Freezing has probably not destroyed the semi-permeability of the integument. Frosted seeds in all cases absorbed more rapidly and larger amounts than non-frosted seeds, this difference being probably due to the presence of greater amounts of sugar in the frosted than in the non-frosted seeds.

The less mature the wheat at the time of exposure to freezing temperatures the greater was the increase in absorptive capacity brought about by the freezing, and the greater was the effect of the frost on the kernel.

Peat Land Farming

By F. J. ALWAY

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In their origin, chemical composition, physical properties and agricultural history, peat soils differ very widely from ordinary or mineral soils, and attempts to farm them by methods successful on mineral soils have usually led only to disappointment. On mineral soils, which are found in every country, state and province, the art of agriculture had reached a high state of development before the dawn of history. The formation of peat soils is dependent upon certain climatic and drainage conditions, and as a result they are absent from many countries and there is no record of any successful attempt to bring them under cultivation before the discovery of America, while the solution of the problems of their successful management is more recent even than the Franco-Prussian war and came as a direct result of the application of scientific methods and the fruits of agricultural science.

Characteristics of Peat

Peat consists of the more or less decomposed remains of plants, and in a fresh state forms a soft, moist mass, light brown to black in color. In some peats the parts

of the original plants may be recognized by the naked eye, or with the aid of the microscope, but in others the processes of decomposition have proceeded so far that the plant structures are no longer distinguishable. The latter are referred to as *well decomposed*, and the former as *poorly* or *slightly decomposed*.

When sufficiently dry, peat may be ignited, the organic matter burning away, leaving behind only the mineral portion or *ash*, which varies within wide limits, in some cases being as low as five per cent.

The relative proportion of organic matter serves to distinguish peat soils from mineral soils. In the latter it rarely exceeds ten per cent, while in peats it usually is well above seventy per cent and for many feet from the surface may show no decrease with increase in depth.

Peat, Peaty and Muck Soils

Peat lands are those on which the peat layer is so thick that after drainage, and the consequent shrinkage of the surface layer, there remains peat at least 8 inches in thickness, enough to prevent the plow bringing the underlying mineral soil to the surface. The term *peaty soil* is employed where the blanket of peat is so thin that the plow turns up the underlying sand, loam or clay.

The term "muck" is used instead of, or interchangeable with, "peat" in many places, but technically it is applied only to those soils in which either there is a high proportion of mineral matter or the plant residues are so thoroughly decomposed that little or none of their original structure is recognizable. As it is desirable to distinguish between peat and muck on the basis of the content of mineral matter rather than the degree of disintegration of the plant remains, the term *muck* is better confined to soils containing more than fifty per cent of ash. Only a small proportion of our peats carry even as much as thirty per cent of ash, and many as little as ten per cent. Muck soils, so defined, are not extensive, but they need to be recognized as such and to be distinguished from the typical peats. As the proportion of ash in the mucks increases, they more closely approach the mineral soils in chemical composition, physical properties and methods of reclamation and management.

Supply of Plant Food in Peat Soils

In their supply of potash, phosphoric acid, and nitrogen, peat soils in general differ markedly from mineral soils. The amount of potash is usually very small, so small indeed that in many cases it would be quite exhausted by two or three good crops, and in the analysis of peats it is rarely considered worth while to determine the amount of potash, it being so low. While the proportion of phosphoric acid is usually much higher, it is largely unavailable, being combined with the organic matter in such a form that it can be used by the plants only after it has been set free by the destruction of the organic matter, either through decay or by burning.

The content of *lime* is more variable than that of either potash or phosphate, and on bogs that are very low in lime most crop plants fail, even when given liberal applications of nitrogen, potash and phosphate fertilizers. The peat of most Minnesota bogs is so abundantly supplied with it that there is no probability of their ever running short of lime. In fact a bog which is not lime deficient when first reclaimed is not likely ever to become lime deficient.

In *nitrogen* all peats are very rich, containing from 1.3 to 4 per cent, compared with 0.1 to 0.4 per cent in fertile mineral soils. On high-lime peats nitrogen fertilizers not only are unnecessary for ordinary farm crops but often fail to cause any distinct increase in yields. Such soils may be cropped indefinitely without fear of exhausting the nitrogen, the constitutent first to become deficient in most mineral soils.

On lime deficient peats, although the nitrogen is abundant, it does not readily pass into an available form, and with crops other than legumes it is necessary to apply

a nitrogen fertilizer for satisfactory yields. Clovers do not succeed on the low-lime peats until lime has been applied, together with phosphate and potash, if these are deficient, as is practically always the case.

High-lime and Low-lime Peats

Thus the proportion of lime in a peat soil determines the sufficiency of the supply not only of the lime itself but also of the nitrogen. Accordingly, it is such an important factor that peat soils, and hence bogs, may be divided into two classes, so far as their reclamation and fertilization are concerned, viz.: high-lime and low-lime. The former are those on which no benefit is derived from liming and the latter those on which most crop plants fail unless lime is applied.

Table I shows the composition of six typical Minnesota peat soils, the first two belonging to the *low-lime*, or lime-deficient group, and the others to the ***high-lime*** group, as shown by experiment.

TABLE I

COMPOSITION OF SOME TYPICAL PEAT SOILS

Source	Organic Matter (Per Cent)	Mineral Matter, or Ash (Per Cent)	Nitrogen (Per Cent)	Lime (Per Cent)	Phosphoric Acid (Per Cent)	Potash (Per Cent)
(*a*) Low-lime Peat—						
Rice Lake	94.0	6.0	1.70	0.31	0.16	0.04
Grand Rapids	93.0	7.0	2.22	0.40	0.18	0.07
(*b*) Peat of Doubtful Lime Requirement—						
Forest Heights	79.5	20.5	2.92	1.01	0.38	0.09
(*c*) High-Lime Peat—						
Goodridge	79.8	20.2	2.78	3.25	0.24	0.10
Golden Valley	87.7	12.3	2.68	2.59	0.25	0.07
Waterville	59.7	40.3	2.35	2.52	0.36	0.17

In computing the amount of plant food in the surface soil it is important to bear in mind that peats weigh much less than mineral soils. While a cubic foot of the latter when dry weighs from 70 to 100 pounds, the same volume of dry peat weighs only from 7 to 50 pounds. The higher the ash content and the better decomposed and more compacted a peat is, the more it will weigh when dry.

How to Distinguish High-lime From Low-lime Peat

Most of the peat land in Minnesota belongs to the high-lime group and but little attempt has been made to bring the low-lime peat under the plow.

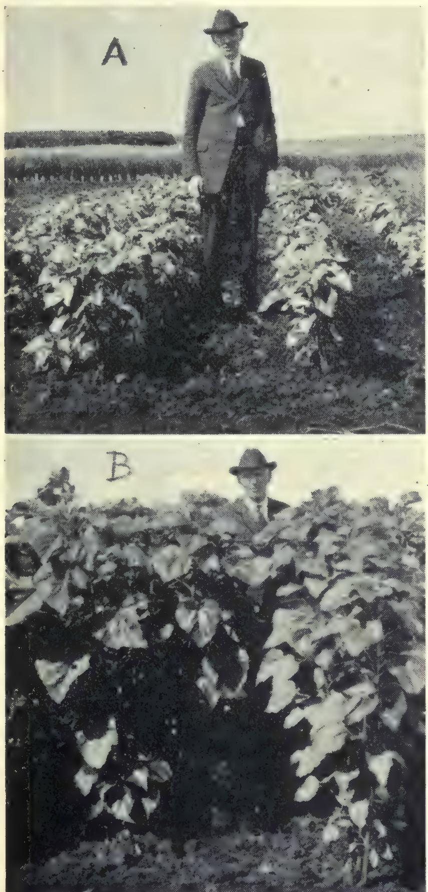
If either alsike or red clover makes a good growth on the untreated land, liming is not necessary. Even if the plants appear stunted, if they are able to live over winter and retain a healthy color there is usually no lack of lime. If there is any doubt, a laboratory test should be obtained.

If a *reliable* test for acidity, using either litmus paper or the Truog method, shows that the peat is not acid, or is only slightly so, no further chemical examination is needed in order to answer the question, it being safe to assume on the strength of this that it is a high-lime peat. If the Truog test shows the soil to be ***intensely acid***, it is almost certain that liming will be necessary, but in this case an actual determination of the lime content is desirable. If the test shows only a moderate or strong acidity, it is advisable to have a quantitative determination of the lime.

If the lime (CaO) content amounts to 1.5 per cent or more, no matter what the litmus or Truog test may show, it appears safe to assume that liming will not only be useless but liable even to lower crop yields. If the lime content is less than 0.6 per cent, it is safe to conclude that liming will be absolutely necessary for clover, timothy, and most other farm crops. If it lies between 0.6 and 0.9 per cent, it is quite probable that liming will be necessary, and if between 1.2 and 1.5 per cent, equally probable

that it will be unnecessary. This leaves as purely dubious only those peats with a content of between 0.9 and 1.2 per cent of lime, as illustrated by the third sample in Table I. Only a very small part of all the Minnesota peats so far examined have been found to fall into the doubtful class. To decide as to the need of lime in such cases, a field or vegetation experiment is necessary.

A carefully conducted vegetation experiment (as illustrated in Figures 1 and 2) with the peats of this last, dubious class, using red clover or sweet clover as a test crop, may be expected to answer the question. For this from two to four months are required and much labor is involved, as well as especially skilled supervision with unusual precautions. A pot test in unskilled hands, or under unfavorable conditions, is likely to be misleading, and hence worse than useless. Any intelligent farmer can carry out a field experiment, and the answer will be forthcoming in two or three months at most.



Where phosphate only is needed.
Sunflowers on adjacent plots on peat soil at Golden Valley, Minnesota, August, 1922
A. Without fertilizer. B. With phosphate.

Four Classes of High-lime Peats

According to the fertilization needed when first brought under cultivation, high-lime peats form four classes:

1. Those needing no fertilization.
2. Those needing phosphate only.
3. Those needing potash only.
4. Those needing both phosphate and potash.

(1) *Peats Requiring No Treatment*—Some of these are found south of St. Paul, but on most of them both potash and phosphate will probably be required within a very few years. On some very shallow bogs, or where the peat is really a muck, the need of fertilizers may not develop any more rapidly than on mineral soils.

(2) *Peats Needing Only Potash*—These appear to be rare, being confined to those with an especially high content of phosphate, 0.50 per cent or higher.

(3) *Peats Needing Only Phosphate*—These are very common in northwestern Minnesota and are to be found elsewhere in the state, but it is safe to expect that potash fertilization of these cannot be avoided for more than the first few years except where the peat is very shallow. On soils of this class potash shows no distinct effect at the first—neither beneficial nor harmful.

(4) *Peats Needing Both Potash and Phosphate*—These are the most com-

Where phosphate only is needed.
Oats on adjacent plots on peat soil at Golden Valley, Minnesota, August, 1921.

mon. Many of them are much improved when given only potash, but phosphate along with the potash is needed for really satisfactory yields. Peats of this class when treated with phosphate alone often have the crop yields actually lowered.

On high-lime peats the supply of readily available ***nitrogen*** seems likely to last as long as the peat, and the only place where nitrogen fertilizers may be expected to find a profitable place is with certain truck crops, such as lettuce, celery and onions.

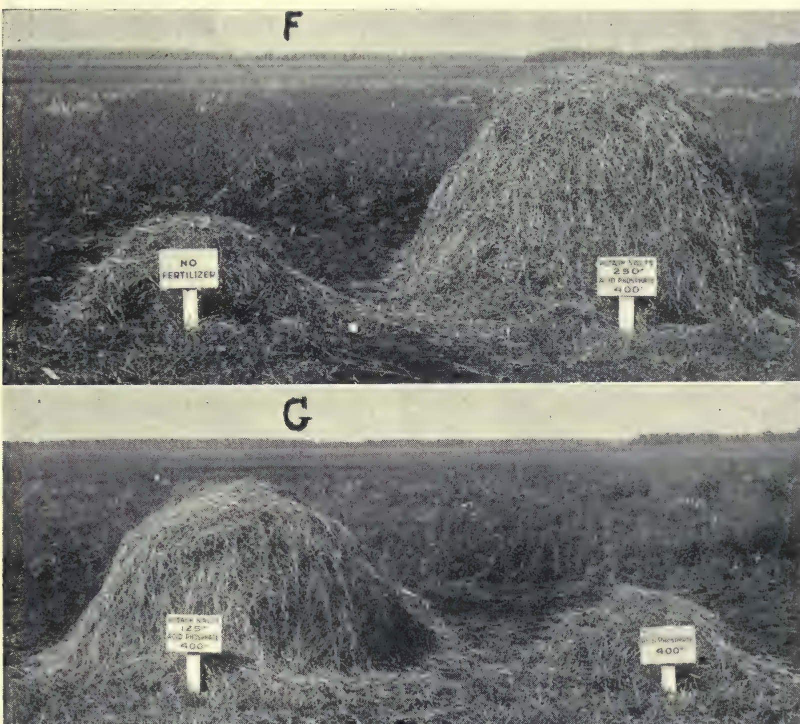
Farm manure, which furnishes nitrogen, potash and phosphate, may be employed to fertilize peat soils, but usually it can be used more profitably on mineral soils where its content of nitrogen is especially valuable and where the organic matter which it supplies is usually of distinct benefit. On the high-lime peats the nitrogen often gives little crop increase and the organic matter is useless. A ***light application of manure*** is desirable on newly broken peat in order to furnish organisms of decay.

Deciding Upon Potash and Phosphate Requirement

If liming is necessary, both phosphate and potash must practically always be added, and, except for legume crops, also a nitrogen fertilizer. Where a non-leguminous crop, such as timothy or blue-grass, is grown in a mixture with a clover, the latter, when inoculated, may provide all the nitrogen needed by the non-legume as well as by itself.

Potash Salts 500 lbs.	Potash Salts 500 lbs. and Acid Phosphate 400 lbs.	Acid Phosphate 400 lbs.	No Fertilizer

Where both phosphate and potash are needed. Potatoes at Coon Creek, Minnesota, 1919



Where both phosphate and potash are needed.
Clover—timothy hay at Coon Creek, Minnesota, July, 1920.
Phosphate alone is without benefit

If the peat is of the high-lime group, the only really satisfactory way in which to decide upon its potash and phosphate needs is by means of a field trial, or co-called plot experiment, on land that has been properly drained, plowed and worked down to form a good seedbed. If the weather is moderately favorable and suitable trial crops are selected, a single season will suffice to answer the question. Such trials are to be recommended to everyone who is working peat lands, and usually it is very unwise to put any large tract into crop without first having tried such an experiment.

When Field Trials Are Advisable

Where one is already securing excellent yields without the use of manure or commercial fertilizer, he scarcely needs an examination of his soil. But where the seedbed has been well prepared and suitable crops have been tried without satisfactory yields, a field trial should at once be arranged. If, however, the reclamation work has progressed only to the point of getting the land drained, plowed and ready for planting, the most of the prepared land should be put into crops that suffer least from lack of proper fertilization, such as flax and buckwheat, or into those that are best able to survive, such as a mixture of grass and clover, until an experiment on a small part of the field has indicated the proper treatment.

Such experiements are out of the question where no land has been prepared for crops, and in this case the owner must trust for information to the results of laboratory investigations, interpreted in the light of what field experiments there may be on peats of similar character in his locality.

Crops For Peat

Summer frosts are very common on peat soils even as far south as St. Paul, and this greatly limits the choice of crops. Grasses and clovers do well, and in mixed farming the growth of these for both hay and pasture should be counted upon as the main use of the peat land. These soils are especially suited to certain hardy truck crops, especially lettuce, celery and onions. Potatoes give good yields when early frosts do not occur. Of the small grains flax and early sown winter rye appear the best as the first crop after breaking, and oats does better than barley. Wheat is not to be recommended.

In northern Minnesota all crops tried on peat that had been neither manured, fertilized nor burned, have been failures, except flax, which alone has been a complete failure on burned land.

Drainage

Drainage is the indispensable first step, and it is important to remember that there are bogs and bogs and that a drainage scheme suitable for one may be entirely unsuited to another. Where the peat is shallow, as from only one to three feet deep, and has a porous soil underneath, shallow open laterals at wide intervals together with deep roadside ditches may suffice, but where the peat is deep, or where the water lies close to the surface, it generally is necessary to employ numerous laterals, either open ditches or preferably tile lines. The latter do not interfere with cultivation and cost much less to keep in working order, although they require a much greater expense at first.

The distance between laterals will depend upon the character of both the peat itself and the underlying layers—clay, sand or gravel—especially where the peat is not deeper than the deepest ditches. Ordinarily, in order to make the land dry enough for cultivated crops and grains, the laterals should be from 60 to 160 feet apart, but for permanent meadows they do not need to be so close together. Where the bog is everywhere underlaid by sand that is tapped by large open ditches, and the seepage from the

surrounding mineral soils is intercepted by ditches or tiles, it is sometimes unnecessary to put in any laterals.

Clearing

Clearing is the next operation if the bog is covered by trees or shrubs. In many cases this is very expensive, especially where the surface layers are full of old roots, stumps and logs. It is not safe from surface appearances to judge as to how expensive the clearing and preparation of the seedbed may be.

Breaking

Where the bog is naturally covered by grasses and sedges, it may be best broken 8 or 9 inches deep by a tractor drawing a 20 or 24-inch breaking plow with moldboard extension, leaving the furrow slice turned over as flat as possible. Where a gang is used, narrower plows will do, but the moldboard extension should be used. The style of the coulter will depend upon the character of the peat. If this carries little or no wood, the rolling coulter is best, but where it is full of roots and logs one of the knife forms may be necessary. If the surface is so full of wood that even this will not work well, resort may be had to a strong disk plow.

Where wood is encountered, it should be gathered, following the plowing, and either burned in piles or removed for fuel. Ordinarily, the removal of this will be a much lighter task if it be allowed to lie on the surface for a few days to lose much of the water it carries when first plowed out.

Rolling

As soon as possible after breaking, the land should be gone over with a heavy concrete roller, or, if this is not available, with a weighted disk with the disks set straight. The wheels of heavy tractors exert a similar rolling effect. The compacting of the furrow slices greatly assists in killing the wild grasses and shrubs, hastens the decay of the sod and much simplifies the later preparation of a good seedbed. Where much wood has been brought up by the plow, it is usually better to remove it before rolling.

The roller may be of solid concrete, or a shell of concrete or iron filled with removable concrete blocks, or it may be of iron with water filling, the only essential being that it should be sufficiently heavy to exert a pressure of about 1600 pounds per yard of length.

In the subsequent cultivation the disk, either the plain, cutaway or spading form, is the most important implement, second only to which is the heavy roller. The latter should be used on meadows and pastures as well as on fields being prepared for crop.

Fertilization and Liming

With the land drained, cleared, plowed and rolled, the next operation is that of fertilization, liming or both. It is folly to spend money in draining, clearing and plowing unless one is willing to go to whatever expense is necessary in order to overcome the chemical deficiencies of the soil, and as a rule it is very unwise to prepare a large tract of peat land for crop until its chemical deficiencies have been ascertained.

When considering the chemical treatment needed by any particular tract of peat, we should distinguish between what must be applied when the land is first brought under cultivation and what may be needed later, as at times fertilizers which are unnecessary in the first year, or even for several years, may later become indispensable.

Low-lime bogs should be given a dressing of two or three tons per acre of ground limestone, or its equivalent in the form of burned lime. This should be well worked in with the disk some little time in advance of seeding. Later applications of about one ton per acre once in three to five years are desirable.

Rate of Application of Fertilizers and Lime

Until experiments have been run long enough to determine what quantities of the different fertilizers will prove most profitable under different conditions, we can do no better than be guided by the results of the experiments conducted in Germany, Austria and Sweden, as indicated in the accompanying table. (Table II).

TABLE II

RATES OF APPLICATION OF FERTILIZERS AND LIME ON PEAT SOILS

Application	Rate per Acre High-lime Bog (Pounds)	Rate per Acre Low-lime Bog (Pounds)
First Year of Cultivation		
Ground limestone	None	4000 to 6000
Acid phosphate	400 to 1000	1000 to 1500
Potash (muriate)	200 to 400	400 to 600
Nitrate	None	250 to 400
Second Year		
Ground limestone	None	None
Acid phosphate	300 to 400	600 to 1000
Potash (muriate)	200 to 250	200 to 250
Nitrate	None	200 to 300
Third Year		
Ground limestone	None	None
Acid phosphate	150 to 300	600 to 750
Potash (muriate)	100 to 150	200
Nitrate	None	250
Fourth Year		
Ground limestone	None	1000
Acid phosphate	*Replacement	*Replacement
Potash (muriate)	*Replacement	*Replacement
Nitrate	None	250

For simplicity it is assumed in the table that ground limestone, muriate of potash, acid phosphate and nitrate of soda are the only forms employed. The actual amount of other forms recommended would depend upon the concentration of the fertilizer.

Where one is using much fertilizer, it is advisable to secure a drill with fertilizer attachment, but where only a small amount is used, and in trials, it may be scattered broadcast by hand and disked in just before planting the crop. If stable manure is employed, from 10 to 30 tons per acre should be used on high-lime peats and the same amount together with the necessary ground limestone or burnt lime on low-lime peats.

Water Level Control

One of the most important considerations in favor of drained peats with a controllable water-level is that when in hot, dry summers the hay is light and the pastures short on the surrounding mineral soils these peats may be expected to produce their heaviest yields.

On mineral soils the water may be lowered without fear of over-drainage, but on peats, in the case of meadows and pastures, the yields are often seriously lessened by excessive drainage. The level at which the water should be kept will differ somewhat according to the weather of the crop season, but in general it may be assumed that for meadows a distance of about 20 inches below the surface will be best. For pastures

*The quantity needed to replace that removed in the crop of the previous year.

it must be lower, about 30 inches, in order that the surface may be firm enough to bear the weight of the pasturing animals, and for cultivated crops and grains it should be not less than 40 inches. In very wet seasons there may be no advantage, even on meadows, in keeping the water so close to the surface, but it is probable that in the course of a series of years the yields will average so much higher where the water level is regulated that provision should be made for such control when a drainage system is being installed. Where small open ditches are in use, the water may be raised by simply throwing in a few sods and tramping them down, removing them when it is desired to lower the level. In many cases, however, when the drainage system lowers the water much below the desired depth, during times of drouth there is no in-flow from the surrounding lands by means of which the water-level can be raised.

Burning

Burning the surface layer of peat is in some cases desirable and at times is very profitable, but it should be practiced only after a careful consideration of the local conditions. Burning may ruin the drainage system, produce an alkali soil, leave a boulder field, or in the case of shallow peats, leave too little organic matter for a good seedbed. In the first season after burning the crop results are usually excellent, but unless the peat layer is shallow and underlaid by a good mineral soil the beneficial effect will rapidly become less and may even entirely disappear at the end of the first season. In burning, extreme precautions should be taken to prevent the escape of fire.

Where an accidental burning has rendered clearing operations easy, the land should be cleared and put into some crop before wild vegetation has occupied the surface. A clover-grass mixture is one of the most suitable crops for this purpose.

Where the peat layer has been removed by fire, the underlying soil, if a loam or clay, may be farmed by the ordinary methods used on mineral soils.

Profit of Present Reclamation

It appears that at present, in the case of the greater portion of Minnesota's immense peat acreage, the profit of reclamation is to be regarded as extremely doubtful, even under the most skilled supervision and with every resource and facility for conducting the work economically, while many extensive tracts could be improved only at a loss. There is, however, much peat land that might at once be profitably reclaimed, especially where the owners already live upon it or where it forms parts of farms consisting largely of mineral soil. In Manitoba conditions are less favorable for profitable reclamation at present. In general, the wise method of procedure appears to be for those men already living upon farms which have more or less peat land, either already provided with, or convenient to outlets, to try out at once the complete reclamation of a few of these unprofitable acres, making use of modern methods.

Method of Procedure Advised

Extensive ditching projects far in advance of reclamation, which have been common in northern Minnesota, were due to the formerly prevailing erroneous belief that drainage alone would make the peat lands productive.

When immediate reclamation is not purposed the grass covered bogs had better be left to serve as wild meadows, or, if too wet, drained just enough to allow the cutting of wild hay, while the bogs with merchantable timber should be kept under proper forest management, and all others left undisturbed until the would-be developers have satisfied themselves by systematic investigations and small-scale trials that reclamation is likely to prove profitable.

Soil Colloids

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The term "colloid" does not refer to a definite class of substances in the same sense as the terms, "metal," "acid" or "salt" are used, but refers to a physical state of division in which a substance may exist. It is thus possible for any substance to assume the colloidal state provided the size of its particles can be brought within certain limits. The term "colloid" means glue or jelly-like, and was formerly used in contradistinction to "crystalloids" which substances crystallized from solutions and diffused through membrances as animal or parchment, while members of the colloid class did not form crystals and diffused through membranes slowly or not at all. Their separation was made comparatively easy because of the great difference in rates of diffusion. A separation in this way is termed "dialysis." Formerly all substances belonged to the one or other of these classes; although the terms crystalloidal and colloidal are yet used they have at present a different meaning.

Familiar examples of substances in the crystalloidal state are sugar, salt and saltpeter, and of the colloidal state are glue, gelatin and egg albumen. Solutions of substances of these two states of division possess entirely different properties. A solution of sugar or salt in water will lower the temperature at which the water will freeze, will raise the temperature at which the water will boil, and will permit the passage through it of a beam of light without the path of the ray becoming visible to the eye. A solution of gelatin will neither lower the freezing point or raise the boiling point of water to any great extent and the path of a beam of light through the solution becomes visible to the eye.

In the case of the sugar and salt solutions, the particles of sugar and salt are sufficiently small as to have a pronounced effect upon the properties of the water and also so small that light is not scattered or reflected, rendering visible its path through the solution. Such substances as these which exert an influence upon its solvent are said to be in the molecular state of division, or in true solution. In the case of the gelatin solution the particles of the gelatin are larger than those of the salt and sugar, hence do not affect the properties of the solvent. They are, however, sufficiently large to obstruct somewhat the passage of a beam of light, hence their scattering effect renders the beam visible to the eye. This is known as the Tyndall effect. This property is well illustrated by the entrance of a beam of sunlight through a crack or slit into a darkened room, the air of which contains dust particles. The path of the light is visible because of the scattering and reflection of the light by the small dust particles themselves which are in the path of beam. It is the size of particle, larger than the ordinary molecule yet sufficiently small to remain in solution, which gives the colloidal state or condition.

As the size of the particles increases from that range of sizes which gives colloidal solutions, there is approached the sizes which give first fine suspensions, and then the more coarse suspensions. The idea of suspensions is obtained if a little soil is thoroughly stirred up with water and then let settle. The larger and heavier particles will settle out immediately. Then the subsidence of the particles of the smaller sizes will gradually follow, and the time required for the total subsidence of the extremely fine soil particles will be in inverse proportion to their size. The finer the particles held in suspension, the more nearly do they approach the colloidal state and solution.

It is now believed that suspensions, colloidal solutions and true solutions represent varying degrees of dispersion of the solute or the substance dissolved, all three types being termed "dispersoids." Thus we have all degrees of dispersibility from suspensions

which grade from the coarse non-homogeneous through finer suspensions which appear homogeneous and colloidal solutions to true molecular solutions. The following scheme will picture this relation, and the limits given are the sizes which are now generally accepted and used.

DISPERSOIDS (After Ostwald)

Coarse Dispersoids (suspensions, emulsions, emulsoids)	Size of particles greater than .1 μ*.
Colloidal substances (solution or gellies)	Size of particles .1 μ to 1 $\mu\mu$*.
Molecular Dispersoids (crystal form or in solution)	Size of particles about 1 $\mu\mu$ and smaller
Ionic Dispersoids (solution)	

*Greek symbols $\mu = .001$ millimeter.
$\mu\mu = .000001$ millimeter.
1 millimeter = 1-25 inch.

From this scheme it is easily understood why many substances, as starches, proteins, protoplasm, gums and resins, fall in the colloid region for their molecules. The molecules of these substances are enormously large, and hence do not behave as other molecules of much smaller size.

Some general properties of colloids can be taken up with advantage before considering the colloids of the soil. Colloid particles in solution have been found to possess or carry electric charges, either positive or negative, as the case may be. The nature of the charge varies with the solvent used. The particles of colloidal aqueous solutions of arsenious sulphide, gold and silicic acid, for example, are charged negatively, while those of ferric hydroxide are charged positively. This property is demonstrated by placing colloidal solutions in an electrical field when the colloidal particles will migrate to one or the other pole. If two colloidal solutions of opposite charges are brought together or mixed, a precipitation or coagulation of the particles occur. This is explained by saying that when the electrical charges on one set of particles are neutralized by the charges of opposite sign on the other set of particles, the particles are made electrically neutral, and then settle out together and grow into larger clumps which form the precipitate. It has been suggested that it is the repellent action of like charges on the particles in a colloidal solution which keeps them in a dispersed condition. Two colloids of the same electrical sign would have no coagulating effect on each other. However, if to a colloidal solution an electrolyte—a substance which conducts electricity—is added which furnishes charges of opposite sign, coagulation also occurs. The coagulating power of an electrolyte depends upon the amount of charge carried on the positive ion if the colloid is negatively charged, or negative ion if the colloid is positively charged.

When colloidal solutions are considered with reference to precipitating agents, they may be divided into two classes; namely, emulsoids and suspensoids. The former give with water viscous gelatinizing mixtures which are not coagulated by electrolytes. Gelatin may be taken as an example of this class. The latter give with water non-viscous mixtures which readily coagulate on addition of small amounts of electrolytes.

Colloids, when in solution, are often called "hydrosols" or "sols." When in the gelatinous amorphous form, they are called "hydrogels" or "gels." Those colloids which can be made to pass easily back and forth from gel to sol are known as reversible, while those which cannot are called irreversible colloids. The flocculation of soils by lime is related to gel formation.

Everyone is familiar with the property of finely divided charcoal for adsorbing gases and also substances from solution. If a colored solution is allowed to pass through a layer of such charcoal, the substance giving the color is removed and held to the surfaces of the small particles. Charcoal is used in this way for clarifying sugar solutions

in the sugar industry. The finer the particles, the greater is the power of adsorption which is directly related to the extent of surface area. It has been estimated that 1 gram of high grade adsorbing charcoal has a surface of from 100 to 1000 square meters. Colloids possess great surface area—and hence their power of adsorption is very great. This explains in a great measure the power of the soil for purifying water as it filters through.

Colloids in the Soil

The colloids in the soil can be classed under organic and inorganic heads. The organic matter of a soil is largely colloidal, and it is in this state that the so-called humic bodies occur. The inorganic colloidal materials are made principally of the iron and aluminium hydroxides, silicic acid and various silicates of aluminium.

Formation of Soil Colloids and Constitution of the Soil

The organic colloids are formed from the decomposition of organic matter through bacterial and chemical processes. Since it is the fresh organic material that undergoes the most active decomposition, it is only the older organic material most resistant to decay that remains in a soil for any considerable time. It is to these stable organic compounds, black in color and earthy in appearance, that the term "humus" is applied.

The inorganic colloids are formed from the weathering of rocks and the further breaking up and decomposition of soil particles. It is believed that most inorganic colloids arise from chemical weathering, although glacial and any subsequent grinding action would be a contributing agent. For example, in the decomposition of feldspar rock through the chemical processes of carbonation and hydration, kaolin and silica are produced. These products are found in part as colloids. Rocks are composed of one or more minerals, and it is usually the case that where two or more minerals are present, one of them is more readily attacked by weathering processes than the others. The formation of colloids are thus produced along with the formation and disintegration of the larger soil particles.

Soil colloids may exist in the soil in one or more ways. It is possible for soil particles to be coated by a colloid layer. If colloids result from chemical weathering, it seems very natural that on the surfaces where such action is going on colloidal substances should be found. If the mineral orthoclase is subjected to wet grinding and the very fine particles are then stained with the proper stain and viewed under a microscope, there is presented a halo appearance immediately around the mineral grain. It appears that the nature of the material around the grain is very different from that of the grain.

Another view is that the soil particles themselves are in the colloid phase. This is undoubtedly true in the case of the so-called very finely divided or ultra clay in extremely heavy clay soils.

The soil particles, or at least part of them, are sometimes regarded as being made up of a mixture of materials. In this case any colloidal material would serve as a binding agent to cement together the heterogeneous mass.

Soil Colloids and Soil Properties

Soil properties are closely related to or dependent upon colloidal conditions. Good soil management consists largely in favoring or controlling colloidal development. In a heavy clay soil there is danger of the colloidal condition being developed too far, while in sandy soils it is desirable to favor this development as far as possible. Since the colloidal condition is a physical condition, it is the differences in physical properties of soils that are most evident.

Physically the fundamental difference in soils is the size of the soil particles and their arrangement. The former is known as texture, the latter as structure. Grading

from sand through silt to clay the particles become smaller, and so there is in clay soils the greatest colloidal development. It is to this condition that the marked properties of clay soils are due, as their plasticity when wet, cohesion when dry, power of adsorption, and ability to retain moisture.

Plasticity may be defined as that property of materials which permits a change of form, or, as commonly expressed, that property which permits of moulding. The degree of plasticity varies, depending upon the ease with which the particles may move over one another, and so any factor which affects this movement will effect plasticity. Colloids, especially those of a gelatinous nature or in a gel state when sufficient moisture is present, behave as a lubricant, and so make easy this freedom of particles to move, yet they cohere sufficiently to prevent disruption of the mass. This explains the greasiness and stickness of clay soils when wet.

To the degree that clay soils are plastic when wet, so is cohesion developed when dry. This effect is familiar in granulation and the difficulty with which clay granules or clods are pulverized. On drying, colloidal material contracts in volume, and when wet it will again increase in volume. This shrinking and swelling property is illustrated in the alternate drying and wetting of gels as gelatin. The cracking of soils when dry is due to such contraction. The size of clods or granules formed in the drying of a clay soil depends upon the lines of weakness existing throughout the mass along which cleavage may take place. Alternate wetting and drying or freezing and thawing will promote formation of lines of weakness.

In the management of clay or heavy soils, the thing desired is to secure good soil structure and tilth and to maintain this condition. Working clay land when too wet puddles or breaks down the compound particles which are necessary for good drainage and aeration. In this connection lime is often added to these soils to improve their physical condition. Lime here functions as a precipitating or flocculating agent of colloidal materials. This action is undoubtedly similar to the precipitation of a suspensoid sol to the gel form by an electrolyte. In the coagulation of soil colloids soil particles would be immeshed and so promote the formation of the larger soil aggregates.

The adsorptive power of soils is a very important property. It is directly related to extent of surface area. A cubic foot of granite rock in cube form has a surface of six square feet. The particles in a cubic foot of sand have a surface of 60,390 sq. ft. (approx.) and in a cubic foot of clay 154,275 sq. ft. (approx.). In the application of soluble fertilizers to soil they are probably first adsorbed, and so held in the surface layer of soil where most of the plant roots feed. Not all substances are adsorbed to the same degree. Adsorption by pure charcoal or any other inert finely divided material, is purely a physical process. However, the fixation of soluble substances in the soil is not wholly due to adsorptive, but also to chemical processes. It is difficult to say where one process leaves off and the other begins, because of the complexity of processes in the soil.

A clay soil or a soil high in organic matter possesses high water holding capacity. Most of the organic matter in soil is colloidal in nature, and hence possesses the power to retain large amounts of water. The capacity of organic matter to hold water is illustrated in the case of fruit jellies, gelatin jelly or some of the poorer grades of soap where half or more of the total weight is water. The moisture which a plant can use is that moisture which is held by the soil particles in contrast to the free or gravitational water that is free to drain away. This water exists as a film around the soil particles and behaves much as if it were a stretched membrane, depending of course upon the thickness of the film. Water in this state or condition is not as easily lost through evaporation, for as the film becomes thinner the greater is the force which holds it to the surface of the particle. The greater is the surface area in soils, the greater is the

amount of film moisture, and for this reason the smaller the soil particles the greater the power to hold and retain moisture.

The formation of hardpans is often caused by colloidal changes. If a colloidal, soil is changed to the gel form through precipitation and conditions permit of an accumulation of it together with a further drying out of the soil, a hardened layer of soil results, especially so if the gel is one possessing a high cementing property. Pans may occur at various depths in the soil. They may be thick or only thin layers, and may differ widely in their imperviousness. In heavy soils a pan is sometimes formed by the plow sole if repeated plowings are at the same depth. This, however, is a case of puddling.

In the chemical processes of the soil, colloids aid greatly the rate or speed at which these processes or reactions may take place. The more intimately chemical s are mixed either finely ground or in solution, the greater the rate or speed of chemical action. The finer the particles of a substance, the faster it dissolves, for the reason that there is exposed to the solvent a greater surface area on which to act. Colloid particles are extremely small, and so there is a better opportunity for chemical reactions, for the exchange and liberation of bases and acids to the soil solution from which plant roots feed. Colloids behave, then, in a chemical way as automatic regulators of solution of essential elements in the soil. Through the physical process of adsorption, together with chemical reactions, there is prevented the leaching from the soil of those elements which are so important to keep into the soil as potassium and phosphorous. These elements are not ordinarily lost from soils through drainage waters, but, on the other hand, the elements calcium and magnesium, and carbonic and nitric acid are lost quite easily. The following is the order of magnitude of leaching of some of the elements concerned, the first named being leached most easily. Of the bases: calcium, magnesium, sodium and potassium; and of the acids: carbonic, sulphuric, nitric, chloride, silicic, and phosphoric.

In conclusion, the soil should be thought of or regarded as a "mechanism" in which all processes, physical, chemical and biological, work together. The soil is a medium for plant growth and depending upon the relationship of its parts and processes does it approach a perfect medium. Since such a state depends upon the physical and sanitary conditions, water supply, rate of availability of plant food materials and losses through leaching, it is at once apparent that colloids contribute in a large way for the adaptation of a soil to plant needs.

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The Potato Scab Problem

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Perhaps no agricultural subject has received more attention from various investigators of both Europe and America, and certainly none have been more written about, than corky or common scab. All of this more or less contradictory literature, although giving valuable information relative to certain phases of the subject, has not provided any adequate method for control of scab. A scabby crop appears in spite of the most painstaking efforts of growers who adhere to certain advice often published by experiment stations, and a clean crop also appears in spite of the most careless methods which growers are advised not to follow. The result is that confusion and cure-all methods exist among puzzled growers, as well as among many agronomists. A knowledge of the causal organism, methods for control, and the limitation of these methods are important to the agronomist, and certainly of great economic importance to the potato grower.

History

Common potato scab is probably as old as the cultivation of the potato. One of the early theories which existed among many up to about 1895 was that scab was caused by gnats, Hopkins (10). Others thought that various kinds of rubbish, by mechanical irritation, might cause a thickening of the corky layer. Some believed that the caustic effect of certain chemicals such as lime, ashes, manure and other fertilizers, caused the abnormal growth of corky cells. Again, a few believed that much moisture caused an excessive corky growth of the lenticels of the tuber.

About 1890 several investigators, believing that the direct cause of common scab was some sort of bacterial or fungal parasite, endeavored to isolate the organism. Almost simultaneously Thaxter (22), Bolley (3), Humphrey (11), and Gasperini (7) isolated the causal organism from the scab pustules. The description that each gave was essentially similar, but each identified it by a different name. Thaxter placed it among the lower fungi as *Oospora scabies*, and this name has since been adopted by many workers. Gasperini identified it as belonging to the Actinomyces group of higher bacteria and attached the species name *chromogenus*. Actinomyces chromogenus has been used by many plant pathologists to designate this scab organism. Although the generic name of Actinomyces has been finally accepted, the species name of *scabies* has since been suggested as suitable for this particular scab-producing form of Actinomyces, and is also in general use.

MORPHOLOGY—Actinomyces chromogenus—Gasperini.
Oospora scabies—Thaxter.
Actinomyces scabies.

Cultures of Actinomyces chromogenus have been grown with varying success on a large number of media, including cooked potato, turnip, beet and carrot plugs; litmus and plain milk; potato glucose agar with and without peptone added; blood serum, albumen, gelatin, and ordinary agar cultures. The organism actively decomposes peptone, blood, and straw, and uses cellulose as a source of carbon.

This particular scab-producing organism, when grown on common media, appears as long irregular filaments which may be branched much or little. The diameter of the thread varies from one to five microns, and the length exhibits much variation. Under favorable conditions the mycelium grows upward from the culture medium and divides into many short segments resembling rod shaped bacteria. These aerial segments or *gonidia*, as they are called, act as the fruiting bodies, although they are not real spores.

If formed in the soil, the gonidia are easily scattered about by wind, or disseminated through the soil by soil moisture.

The general generic characters of the Actinomyces group is given by Lutman (16) as: "Cells, either short, long, cylindrical, clavate, cuneate in form, which at times may show true branching or long branched mycelial-like filaments, not surrounded by a sheath, without endospores, but with the formation of gonidia-like bodies, due to the segmentation of the cells. Division at right angles to the axis of the rod or filaments; cultures usually may or may not have a moldy appearance due to the development of aerial hyphae; growth may be accompanied by the production of a brown, pink to orange or blue pigment, which may or may not diffuse through the media."

Shapovalov (16) describes the bacterial-like segments as, "These elements called gonidia are short, cylindrical segments of aerial filaments and when mature—*i.e.*, when the aerial growth turns from white to dark gray—will germinate readily. They are 1.5 to 2 u. long and 0.8 to 1 u. broad, with truncate ends. These bodies, when sown in agar, and shortly before germination, become somewhat broader and rounder, sometimes oval or nearly spherical. Germ tubes may be produced at either, or at both ends."

The conditions affecting the production of the fruiting bodies on this organism are both interesting and important, since it seems reasonable to expect that similarly increased or retarded fructification would take place in the soil under certain soil conditions just as readily as in controlled media. Thaxter (23) says: "Under certain conditions these filaments may grow up into the air and become spiral at their extremities and subsequently rather closely septate may break up into short pieces resembling bacteria. This fructification may make its appearance at points on many solid media, especially when the media has become somewhat dry." In this regard Lutman (16) says: "On dry media or in older cultures the septa are more numerous."

Are there other agencies or factors which produce or control the production of these fruiting segments? In reply to this, Lutman (16) says: "We have also observed aerial gonidia on some strains growing on milk and broth, so we are safe in saying that a lack of moisture is not the only factor inducing the production of these segments." Of the many strains of the scab-producing organism, is there a hereditary tendency in some to produce less gonidia than other strains? Lutman (16) says: "A study of a large number of strains isolated from various sources shows that some produce gonidia more readily than others, and that cultures may be selected representing a succession of types from those producing no gonidia, through those showing a moderate amount, to those producing an abundance of gonidia." He further points out that the production or non-production of gonidia is no criterion of the virulence, since both extremes produced scab with almost equal effect. Even if the virulence of the organism may not be at all related to, whether it produces aerial gonidia or not, the question may be asked, "Is the production of gonidia related to the distribution, and therefore the prevalence of the organism in the soil?" It seems reasonable to suppose that it is. Is this abundant gonidia more apt to produce infection of growing tubers than old mycelium? Since all cultures were presumably kept under the same uniform conditions, Lutman does not state whether the amount of gonidia could be increased or decreased in the various strains by varying one such factor as dryness. As it stands it would appear that some strains under the influences of dryness might tend to produce a heavier crop of fruiting bodies than under normal to favorable conditions. If this is so, might it be suggested that a period of dryness early in the season might produce an abundance of gonidia in the soil, and that a rapid distribution of these, and favorable conditions, would increase the chance of the newly formed tuber being attacked? Should this be so to any appreciable extent, we have a problem which might be very profitably investigated.

Temperature

The optimum temperature for growth of the scab organism is given by Shaplovalov (19) to be from 25° to 30° C., retarded and slow below 20°, ceasing to grow at 5°, and the maximum for growth about 40°. Lutman (16) gives practically the same figures—optimum 25°, slow growth below 18° and above 37.5°.

The optimum temperature for germination of the gonidia is given by Shapovalov (19) as from 35 to 40° C. This temperature caused germination in 3 hours, but further growth was very slow. At 20° germination began in 11 hours, at 15° in 18 hours, at 10° in 2 days. At temperatures of 20°, 15° and 10° growth was more or less complete in one week. Now, when a temperature from 10 to 20° C. will produce germination in from 11 hours to 2 days, and good growth in a week, it seems unlikely that higher temperatures for a short period will make any appreciable difference in the amount of fungous growth present in our soils.

Soil temperatures recorded at the University of Alberta station during the summer of 1921, in certain experimental potato plots at a depth of four inches, gave the following averages in degrees centigrade. The range mentioned in the tables is the difference between the dry and moist soils per 10-day period in maximum and minimum averages.

	Average Maximum				Average Minimum				Average
Field Condition	Dry	Med.	Moist	Range	Dry	Med.	Moist	Range	Range
First 10 days	17.8	17.2	16.8	1.0	14.7	14.4	14.4	0.3	.6
Second 10 days	20.9	20.2	19.7	1.2	17.38	16.9	16.7	0.6	.9
Third 10 days	15.8	15.6	15.5	0.3	15.8	14.0	13.9	1.7	1.0
Fourth 10 days	18.5	17.9	17.4	1.1	16.3	15.7	15.2	1.1	1.1
Fifth 10 days	19.4	18.5	17.6	1.8	17.3	16.4	15.7	1.6	1.7
Sixth 10 days	16.2	16.0	15.5	0.7	14.9	14.5	13.9	1.0	.8
Seventh 10 days	16.5	15.7	14.6	1.9	14.2	13.3	13.4	0.8	1.3
Eighth 10 days	15.8	14.3	13.0	2.8	12.3	11.8	11.8	0.5	1.6
Average	17.3	16.9	16.2	......	15.3	14.6	14.37	......	......

	Average Maximum				Average Minimum				Average
Greenhouse	Dry	Med.	Moist	Range	Dry	Med.	Moist	Range	Range
First 10 days	20.49	20.7	20.09	0.4	18.4	18.1	17.8	0.6	0.5
Second 10 days	24.1	23.5	23.8	0.3	20.7	20.8	20.4	0.3	0.3
Third 10 days	21.0	20.8	20.5	0.5	19.5	19.2	18.6	0.9	0.7
Fourth 10 days	22.1	21.2	21.3	0.8	18.9	18.8	18.1	0.8	0.8
Fifth 10 days	22.4	21.1	20.5	1.9	19.9	19.1	18.6	1.3	1.6
Sixth 10 days	19.3	20.4	18.4	0.9	17.1	16.6	16.6	0.5	.7
Seventh 10 days	18.6	18.24	17.4	1.2	16.4	15.5	15.7	0.7	0.9
Eighth 10 days	18.0	17.53	15.5	2.5	15.2	14.5	14.3	0.9	1.7
Average	20.7	20.4	19.6	......	18.2	17.8	17.5	......	......

The above temperatures were taken each day at 8 a.m. and 5 p.m. Water from a barrel was added after the temperature was taken. The summer of 1921 was hot and dry. Moisture content of the soil boxes was determined each four-day period. The plots were also protected from rain.

(*a*) The analysis of the table indicates that soil temperature in a potato patch under field conditions in this district rarely gets higher than 20° or lower than 13°.

(*b*) There was practically no difference in temperature between the moist and dry boxes, whether referring to the maximum or minimum temperatures.

(*c*) The greatest range of average temperatures between the dry and moist soils for any 10-day period was less than 1° in the greenhouse and less than 2° in the field.

(*d*) The average temperature for the dry soil in the field was 16.4° and for the moist 15.3°.

From the data already referred to, and from considerable observation, it appears that temperature does not enter into the scab problem under field conditions in this district to any appreciable extent. The writer has not been able to obtain any literature on the effect of temperature on fructification of the filaments.

Distribution

Actinomyces chromogenus Gasperini is a small but very important branch of the varied flora of normal soils. Botanists, in classifying any genus of plant life, proceed from the species to make the further minor but important divisions of varieties and strains, each possessing certain characteristics. In this particular organism, various workers have presented evidence which indicates a similar classification to be possible, although in such minute organisms there is obvious difficulty in ascertaining the smaller characters. Lutman and Cunningham (16), from greenhouse soil which had been kept very moist, isolated from one gram of representative soil 350,000 Actinomyces albus and 274,000 Actinomyces chromogenus on a 9-days count. Similarly, from depths of 3.6 and 9 inches, in a rich garden soil, on a 9-days count they identified 207,000 A. albus and 466,000 A. chromogenus. They further pointed out that 27 per cent of all the organisms in the soil of the greenhouse and 35 per cent of those in the soil of the garden were Actinomyces of one or the other species, A. albus or A. chromogenus.

Fousek (6) found all the organisms in a loam soil of Austria to consist of from 20 to 30 per cent A. chromogenus and A. albus, in a clay soil from 8 to 15 per cent, and in a sandy soil from 7 to 10 per cent. He further cites this abundant occurrence on the roots of many plants and other decaying organic material. Beijerinck (1) found them in abundance on the roots and in the soil near the roots of all sorts of plants, such as the alder, elm, oak, beech, hazelnut and some forms of ferns. Lutman (16) says: "'It is doubtful if there is any rich garden soil in which A. chromogenus cannot be found in abundance. Indeed, the characteristic earthy odor is one of its products." Other workers indicate the widespread occurrence of the scab producing organism in practically all normal soils, especially those rich in organic food. There is also abundant evidence to show that the scab organism is present in normal virgin prairie soils.

Other Factors of Distribution

Experiments which refer to various methods of spreading the organism or increasing its prevalence in the soil are numerous. Thaxter (26) and others find that horse manure provides a favorable growth medium. Morse (18) planted potatoes in a sterilized soil which was fertilized in one case with manure from a horse and in another from a cow, each fed on scabby tubers. The results show that the organism survived the passage through the digestive tract, and also indicates that more survived from the horse than from the cow. Clinton (4), wishing to determine the increase of scab resulting from planting potatoes on the same soil, reports that in 4 years the scabby tubers increased successively 5 per cent, 22 per cent, 47 per cent to 63 per cent. From what is now known of the peculiar occurrence of scab, it would seem that this particular progression is rather remarkable.

Methods Recommended for Scab Prevention

The following methods of scab prevention have been investigated by various workers.

(1) Fungicidal treatment of soil and tubers.
(2) The application to the soil of various chemicals to retard the growth of the organism.
(3) Crop rotation.
(4) Providing a scab-resistant variety.

The outstanding literature dealing with each of the above methods will be successively dealt with.

Fungicidal Treatment of Tubers—There are certain general points which one must bear in mind when considering the effectiveness of seed treatment:

First, that the usual corrosive sublimate, formalin solution, or formalin gas treatment, providing of course it is thoroughly done, is effective in destroying the organism

on tubers, no matter how badly scabbed. Second, that the scab-producing organism is present in all normal soils in quantities which may vary from slight to abundant, depending on the soil conditions for its growth. Further, it would appear that a soil which does not contain any scab organism must either be too acid, too alkaline, too dry, or else devoid of any suitable food for the bacteria. In this case it would appear that the organism, even if introduced by the untreated tubers, could not long survive or produce appreciable results on the new crop.

When the soil contains an abundance of the organisms, the question is often asked, "Will the addition of a few more organisms on the seed set appreciably alter the amount of scab on the new crop, or add materially to the total scab content of the soil?" In the latter case it seems reasonable that the treatment is practically useless, but in the former case, when the soil is normal and practically clean (a condition which probably is rare), treatment would, theoretically, be of some value. In this "clean" condition, the fact that the parasite thrives on the decaying set would no doubt add to the value of seed treatment. In a soil permeated with the organism, however, this consideration would probably be reduced to zero.

It appears that in deciding the value of many treatments, as interpreted from experimental data, workers should take into consideration all the physical and chemical features of the soil, including scab content and soil moisture, and put less faith in the importance of seed treatment as seriously controlling scab.

Fungicidal Treatment of the Soil—A treatment which aims to kill the organism in the soil is indeed a questionable practice, because any effective treatment would be disastrous to the valuable soil flora, and, added to this, is the excessive cost of chemicals and the obviously extreme difficulty of effective treatment.

Treatments Which Retard or Favor Scab—Under this head much work has been done by Halsted (8), Stone and Chapman (24), Wheeler (27), Sturgis (18), Beckwith (2) and others.

Lime—The general conclusion is that lime increases scab as high as about 40 per cent. Most of the soils referred to were slightly acid, so the increase in scab was probably due to the basic effect of lime.

Lutman (16) cites trials which he conducted (1912-1913) to obtain data on the influence of lime, manure and other chemicals on the scabbing of potatoes. In 1912 lime increased the scab by about 13 per cent, and in 1913 there was a decrease of about 15 per cent. This occurred on land that produced a scabby crop in 1912. Of about ten different treatments he reports but a small increase in the percentage of clean tubers over the controls. These results are strikingly different than those obtained by the previous workers. Speaking of all the treatments, Lutman says: "It is doubtful if these results are at all conclusive. At the present time the only thing that can be said of the results is that no chemical applied for a single season seems, under the conditions obtaining during the trials, to exert any marked effect on the scab organism in the soil."

Lutman's test seems particularly interesting because the writer has found similar results to occur at this station. In 1920 and 1921 a very liberal amount of slaked lime mixed in the soil of three rows gave practically the same amount of scab that the non-limed checks gave. Both years a good crop was harvested and different plots were used each year. In 1920 the tubers had only a trace of scab, but in 1921 they were very scabby. The soil had produced only two crops of oats in its history. All sets were thoroughly treated with mercuric chloride and carefully protected from later infection each year. When checked with flowers of sulphur, green, and rotted manure, no appreciable difference could be determined among all the treatments. Lime, sulphur, and manure all gave similar results, *i.e.*, 1920 almost clean and 1921 quite scabby.

Halsted, on badly scab-infected soil, using full amount of lime, got 38 per cent increase; half amount 3 per cent increase; quarter amount 28 per cent increase; and "scattered in hill" 8 per cent increase. The irregularity of these figures suggests, first, that the amount of lime applied has no vital relation to the increase in scab, and for this reason these figures might all have read 28 to 38 per cent, more or less.

Barnyard Manure—Barnyard manure is generally supposed to encourage scabbing of potatoes. Theoretically, manure should produce acid when decomposing, and thereby decrease scab. On the other hand, manure provides food and possibly other favorable conditions for the growth of the organism. Halsted (8), Sturgis (18), Beckwith (2), Kinney (14) and others indicate that manure increases scab. Lutman (16) got a decrease of about 7 per cent one year and an equal increase the following year. As already referred to, manure checked against no manure at this station did not indicate that manure had any serious relation to the amount of scab produced on the crop, because scab grew abundantly on both the checks and the manured rows in 1921, and in a similar experiment the tubers were quite clean in 1920. From this one might infer that if manure really does favor scab development, this influence may be quite overcome by some other and stronger soil factors.

Wood Ashes—Halsted used 300, 150 and 75 bushels of wood ashes per acre on different plots. There was no difference between his controls and the plots where ashes were used, both being 100 per cent scabby. Lamson (17) got an increase over his control ranging from 0 per cent to 20 per cent on disinfected seed. Wheeler (28) obtained 76.5 per cent increase. The varying results of Lamson and Wheeler again suggest other factors which are possibly always present in such experiments, and which may disturb expected results.

Sulphur—Sulphur has been recommended by some as a valuable retarder to the growth of scab. Stone and Chapman (24) obtained a decrease of 15 to 25 per cent. Halsted (10) reports an average decrease of about 48 per cent and a greater decrease with 360 lbs. per acre than with 720 lbs. Sturgis (22) rolled the sets in sulphur and reports the following decreases: 9 per cent, 7 per cent and 38 per cent. Chester (5), in badly infected soil, reports a decrease of 14 per cent where 300 lbs. per acre were applied, and a decrease of 10 per cent where the sets were simply rolled in the sulphur. These figures suggest that 300 lbs. of sulphur per acre killed or retarded an amount of the organisms in the soil equal to the amount of scab which might have been introduced on the set. It would appear from data at hand that this is not the case, and that there were other factors concerned which have not been considered. Halsted (8) obtained about 42 per cent decrease by using 600 lbs. per acre and the same decrease by simply rolling the set in sulphur. If this could be true, why waste 600 lbs. of sulphur on the soil.. With a large amount of scab in the soil, how could the treated sets protect the new tubers to the extent of 42 per cent, and was the 42 per cent decrease due to either the treatment of the sets or of the soil with sulphur? Beckwith (2) in three different years reports a decrease of about 26 per cent. Lutman (16), using 300 lbs. per acre, got a decrease of less than 7 per cent one year; in another, one row gave an increase, and another gave a decrease, the combined result being about 7 per cent decrease.

In 1920 and 1921 an experiment to determine the value of sulphur was conducted at the University of Alberta. The sets of both check and sulphur rows were thoroughly treated with corrosive sublimate. A quantity of sulphur was scattered over the set and mixed through the soil where the new crop would grow. The results were entirely inconclusive, there being only a slight amount of scab on the control and the experiment. In 1921, although the sulphur was plentiful in the soil about the new crop, the sulphur, lime and manure rows (3 each) were not appreciably unlike—all very scabby. The soil is a normal prairie loam which had produced only two crops of oats. Again,

in another location one-half mile distant and on new soil, a test was made to determine the relative retarding value of ordinary flowers of sulphur and inoculated flowers of sulphur. All sets used were thoroughly treated with strong corrosive sublimate, and each kind of sulphur was scattered in the row about the set and through the soil where the new potatoes were to grow. A splendid crop was produced. The data show that (*a*) scab was produced in abundance in all rows. (*b*) There was no appreciable difference between the ordinary flowers of sulphur and the check row, except on some tubers which came from the soil yellow with sulphur; on these, the size of the spots in some cases was restricted, but not one tuber was clean. (*c*) The scab spots on the inoculated sulphur were distinctly reduced in size, and were about 25 per cent less in number; a few of the tubers were almost clean; all nearly clean tubers were yellow with sulphur; in two cases very vigorous and large scab spots had flourished in clear inoculated sulphur. (*d*) Another interesting feature existing in nearly all the hills of this experiment was the abundance of scab on the under surfaces of the tubers, while the upper surface was often nearly free from spots. This same feature was found to exist to a more or less degree in the lime experiment, and also throughout the field in general.

As far as conditions existing this year (1921) are concerned, sulphur, as a retarder, is only slightly effective. The sulphur used in 1920 also appeared to be useless. Sulphur is expected to supply sulphuric and sulphurous acid by oxidation. Whatever the cause may be, it appears that either oxidation did not take place fast enough, or else other factors were in some way stronger in favoring the growth of the scab.

Kainit has been shown by Halsted (8) to reduce scab from 37 to 42 per cent. On scabby soil it is difficult to see how soaking the seed in a solution of kainit could have the same effect as treating the soil to 1500 lbs. per acre. Again it is interesting to note that both controls and experiments were 100 per cent scabbed when 500 lbs. or when 2000 lbs. per acre were used. Such results lead one to suspect that the seed of the controls had not been treated, or that the controls were not representative enough, and that some of the data do not represent the actual effects of the various materials used. What applies to this seems applicable to much of the work prior to 1900.

In this connection it is interesting to observe that Halsted's work done in 1895 showed a fairly uniform percentage of decrease or increase, irrespective of the wide variation in amount of retarding or favoring material used. For example, all the various lime and manure treatments gave about 30 per cent increase, and all the various sulphur and kainit treatments gave about 40 per cent decrease. This condition is not confined to Halsted's work alone, and suggests that there was some other factor which helped to bring about this uniformity of results.

Crop Rotation—If potatoes are grown successively on the same soil, it is generally expected that the scab content is increased to a high degree because the potato furnishes suitable food for rapid multiplication of the scab organism. Other crops, such as grass or cereals, are supposed to supply less favorable conditions for its multiplication. From this standpoint crop rotation would seem advisable. Crop rotation, however, cannot rid the soil of the scab organism, nor can it ensure a scab-free crop. Indeed, very scabby tubers often occur where the land has been in grass sod for a long period. Again, in some garden plots which receive heavy applications of manure each year, and on which potatoes are grown each season, it has been observed that scab-free crops are frequently produced. Thus, when clean crops are grown on rich garden soils and scabby crops on sod land, it is very doubtful if rotations are nearly so effective as is generally supposed. From data already referred to, all normal soils contain a large count of scab organisms, probably enough at any time to produce a scabby crop if soil conditions are favorable. Hence the question again arises as to whether these "certain"

conditions are not more potent than the supposedly varying scab content of the soil due to rotations on one hand or continual cropping with potatoes on the other.

Disease Resistant Varieties

Resistance to scab depends on both the physiological and the morphological nature of the tuber. The color of the skin, thickness and smoothness of various varieties have been compared as to their susceptibility to scab. Lutman (15), Stuart (20), Beckwith (2), Halsted (11) and others have published data on varietal resistance of potatoes. The results are not conclusive. Stuart says, "Much of the supposed resistance may be due to the accident of place, condition of soil, etc." Lutman (16) says, "Much more confirmatory evidence must be secured before one will be justified in vaunting any particular variety as disease resistant. In a more recent report (Bul. 215, Vt.) Lutman says, "Marked resistance to scab is found in true russet types of tubers. The semi-russet show some scab resistance, while the white thin-skinned varieties seem to be most susceptible."

The following experments conducted from this station should serve as a fair test of the resistance of eight varieties—3 red, 4 white and 1 russet. The same varieties were used on eight experimental plots situated in the Edmonton district. Each variety was planted in two parts of the plot. The data indicate *(a)* that Early Ohio appeared slightly resistant, this degree of resistance depending on the conditions present for infection; *(b)* that the same variety showed less scab in one row than in another in the same plot, and that variations occurred within a row; *(c)* that none of the white varieties plainly showed more resistance than another; *(d)* that over all the plots Russet Gem was entirely clean, irrespective of whether the other varieties were scabby or clean; *(e)* that on one plot where both rows of all other varieties were so scabbed as to be almost unrecognizable from clods, the russet variety was apparently free from any scab spots; *(f)* on one plot a variety would appear more scabby than the others, and on another plot this position was often reversed, thus supporting the possibility that so-called resistance among many of our varieties is often a result of the accident of position.

Other Observations

The writer has been able to make observations on many cases of scab on potatoes, especially over the Edmonton district. These observations have been made over a wide range of conditions, gathered from co-operative experiments conducted with farmers and from potato studies conducted at the University Experiment Station. The following observations are submitted:

1. Scab has occurred on the new breaking of virgin prairie. Here no manure was used and the sets were thoroughly treated with mercuric chloride solution. As scab has occurred in a number of cases, it is safe to assume that the scab producing organism is plentiful in our normal soils.

2. Clean crops have been produced on virgin soils.

3. A crop of clean potatoes has often succeeded a very scabby crop on the same plot.

4. A clean crop succeeded two scabby potato and one beet crop, the soil each year being heavily manured.

5. A perfectly clean crop has been raised on a plot which has received very heavy yearly applications of manure.

6. Scab is repeatedly observed to occur with greater severity on the higher points in a field than in the lower places.

7. Manure, lime and sulphur all produced the same amount of scab in 1920 and 1921.

8. In 1921 it was usual to find the lower part of the tuber badly scabbed and the upper part fairly clean.

The foregoing observations led to the inference that possibly moisture might be directly or indirectly one deciding factor in the production of scab. In order to obtain some data on this inference an experiment was conducted during the summer of 1921. Three series of boxes were arranged in duplicate, two of the series in the greenhouse and one outside. These were protected from rain by tarpaulins. Those outside were set down in the ground level with the surface in order to get field temperature. The boxes were one foot deep, and in order that moisture might be better controlled, the boxes were lined with oil cloth. Water leads enabled water to be added to the bottom of the boxes. Soil that had produced badly scabbed tubers for four years was obtained, thoroughly mixed and used in all the boxes. Each of the series contained duplicate boxes of dry, medium and moist soils—13, 22 and 28 per cent moisture respectively. While the control of the moisture was not all to be desired, the dry boxes gave very scabby tubers, the medium rather intermediate and the moist clean. The experiment, while strongly suggestive of the direct or indirect influence of moisture, does not warrant definite conclusions.

In the dry box, where clean hills occurred at each end and a scabby hill between them, it is thought that moisture was again the deciding factor. Early in the season a sudden storm caused a good quantity of water to run into each end. It was observed that the moisture did not reach the middle hill to the same extent as at the ends. In digging the end hills one tuber from one of these hills was found to reach the vicinity of the middle hill, and it was fairly scabby. In another "wet" box in the greenhouse one tuber reached to the extreme lower corner of the box. When dug the soil was dry about it and the tuber quite scabby. If the amount of moisture or conditions arising from moisture is a controlling factor, it would seem that this might explain the occurrence of scabby tubers in elevated parts of the field and clean tubers on the lower parts. It might also explain the scabby or clean conditions arising in spite of scab-infected soil, large applications of manure, lime and sulphur. Moisture might explain the unequal appearance of scab within a row. It might be a disturbing factor in analyzing the data of scab experiments.

With such meagre data it would seem mere speculation to attempt to explain how moisture tends to prevent scab occurring on the potato. Theoretically, we expect it to favor growth. Does moisture produce enough extra acid to retard growth, or does dry soil favor the alkaline condition? Does a dry condition favor a more abundant production of gonidia? Does a dry condition of the soil allow a better aeration of the soil and therefore produce conditions conducive to the growth of such organisms as might be already established in the tuber? Will an alternation of dry and moist conditions at certain critical times be more conducive to the production of scab than a steady dry condition? Is there a critical time in the growth of the tuber when the scabby or clean condition is determined by environmental factors? If moisture is an influencing factor, how much is necessary and when is the critical time, if any?

The writer has plans of experiments already under way to obtain further information on these questions. The first step aims to determine if moisture is effective, and, if so, what percentage. The second step is to find if there is a critical period in the development of the tuber in relation to the effective moisture content of the soil. Associated with these studies, hydrogen-ion determinations of the soils will be made at various periods; and also an attempt will be made to study the relative amount of the scab producing organisms present in the soil at various times and under the different conditions.

Summary

1. The scab-producing organism belongs to the higher bacteria and multiplies by segmentation of the filaments to form gonidia or fruiting bodies.

2. The organism is present in all normal soils, especially those rich in organic material. It is abundant in some virgin prairie soils.

3. No adequate methods have been found to control scab.

4. Much of the data of experimental work conducted to determine methods of control have exhibited too great a variation to be conclusive, it being often contradictory.

5. Reputed chemicals and other materials which favor or retard scab have often failed entirely to assert their supposed quality. This irregularity strongly suggests other factors which are stronger in controlling or favoring scab.

6. Crop rotation does not seem to be effective in controlling scab.

7. Badly scabby soil which was kept quite moist has produced potatoes absolutely free from scab, and the same soil under approximately the same temperature, but dry, produced very scabby tubers.

8. From experiments and observation it is strongly suspected that moisture is one important factor controlling scab.

9. Experiments are projected to determine the effect of moisture content for controlling scab and the critical period, if any, in the development of the tuber.

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Extension Methods That Get Results

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I am extremely grateful to those who framed the programme for not adding the words "in agronomy" to the subject assigned me, for we have been less successful in this branch of our work than in any other.

I know that the members of your organization can readily adapt to your subject any idea that I may suggest which we have found successful in our other lines of work in Manitoba, and I assume that you prefer me to talk on what we are actually doing rather than to try to work out an elaborate thesis on the ideal condition in successful extension work.

The keynote of our extension work is co-operation, and we have endeavored by, shall I call it "peaceful penetration," to link up with every organization or institution which is in any way related to agriculture until at present we have a direct financial connection with over 500 different bodies in the country. These include 75 Agricultural Societies, 150 Women's Institutes, 250 Boys' and Girls' Clubs, 10 Horticultural Societies and 8 Poultry Associations. In addition, we have a working arrangement with 150 U.F.M. locals and 75 Community Clubs.

Very naturally, a number of these will be represented in one community, and in that case we endeavor to work through a local committee which has representatives on it from each of the organizations included in the community.

Early in the fall a list of subjects on which we can provide speakers is sent to each of the organizations mentioned above, with the request that their local committee number the subjects in the order of preference, also draw attention to evenings already taken, the most suitable hour, etc. The next step is to arrange preliminary drafts

of circuits for the various speakers, keeping in mind the expressed preference in each community.

The schedules, along with a more or less lengthy description of the accomplishments of the speaker, is submitted to the various committees with the request that they be returned before a certain date, with any further suggestions which they would care to make.

It is not often that much adjustment is necessary. The dates having been decided on, a news item is included in the local paper and a letter written to each organizaton, such as the Curling Club, the churches, etc., advising them of the date of the extension lecture, and asking their co-operation in keeping that evening clear. The local committee sends in a list of all the people in the community who would likely be interested in the meeting, and two weeks before the meeting a circular letter is sent to each of the people whose names are sent in. The local committee may, if they wish, get out handbills or a poster and advertise the meeting under their auspices, or the Extension Service will send the posters.

The Boys' and Girls' Clubs and the Extension Service are always on very intimate terms, and the former give great assistance in advertising the meeting and seeing that there is a good attendance.

This may appear to be a lot of work for one meeting, but the main expense is in providing the speaker, and if a good stenographer, by one hour's work, can double the attendance at a meeting, the expenditure is a good one.

Almost all of our agronomy work has been carried on in connection with the Agricultural Societies, mainly because the Act under which they operate enables them to secure financial assistance from the Department of Agriculture. This work is carried on under the following headings:

Plowing Matches,
Summerfallow Competitions,
Standing Field Crop Competitions,
Seed Fairs and
Field Crop and Cleaned Seed Competitions.

Plowing Matches—The plowing matches are now being organized on a three-year basis, as the full benefit of plowing matches cannot be felt in one or two or even three years. Cash prizes are given each year and gold, silver and bronze medals are given by the Provincial Government to the competitors securing the highest average for the three years.

Summerfallow Competitions—There are just two opinions in regard to the summerfallow competitions: one is that they are no good, and the other that they are of the greatest benefit. Those who consider them no good have been trying to use the competition as an agency to compel the farmer to have a clean summerfallow by making him include in it all his summerfallow; while those who consider the competition a success have conducted it as a demonstration. They appointed a summerfallow committee early in the winter. This committee made an exhaustive study of the subject, and then carefully drew up a set of regulations, stating definitely the conditions governing the competition. They then picked out ten farmers whom they knew would be likely to make it a success and asked them to co-operate with them. Ten acres was taken as the unit in size, because they felt that it would be presumption on their part to ask a successful farmer to make radical changes in his method of summerfallowing and adopt a system which at best was an untried idea. He was, however, willing to try out their plan on ten acres and see how it compared with the rest of his summerfallow. Just before harvest commenced an automobile excursion was organized and each farm visited in succession.

The Standing Field Crop Competitions and the Seed Fairs have been very intimately connected, and while they have not produced the results we would have liked, the work done by Minnedosa, Birtle, Warren and Miami Societies alone would more than justify the money spent on the competitions in the whole province. It will be difficult to secure maximum results from this work until some organization backed by the government, as was the wheat marketing board, handles the seed business. Farmers do not seem to want to purchase their seed grain until late in the winter, and the grower cannot hold it until that time. In fact, during the past three years he would have lost a great deal of money had he done so.

The Field Crop and Cleaned Seed Contest is still in its infancy and it is not likely that much headway will be made until someone who is familiar with every detail goes to each individual society for the purpose of explaining its advantages.

During the coming winter two members of the Extension staff will visit a number of Agricultural Societies for the purpose of organizing one or more of the competitions mentioned above.

Smut—I believe that Prof. Harrison's investigations indicate that smut is not increasing in general, but the report of our field crop inspectors shows that there is a marked increase in the number of smutted heads in the fields inspected. Institute lecturers will deal with this subject during the winter season, as it was found that very few people were treating their seed grain for smut.

Certified Seed Potatoes—The problem of marketing Manitoba potatoes has been and is still an unsolved problem. First, because it was difficult to get a carload all of one kind, and, second, because the potatoes were not graded and there was no uniformity in the quantity put in a sack. To meet the first of these problems, the Extension Service imported nine carloads, 6300 bushels, of certified Irish Cobblers from Northern Minnesota and distributed them to 2500 farmers at cost.

The Extension Service co-operated with the Dominion Botany Department in inspecting the field plots, the Extension Service providing four inspectors and the Dominion Botany Department one. Altogether 1000 plots were inspected and about 80 per cent passed field inspection. The tuber inspection is being conducted entirely by the Dominion Botany Department. There is now in Manitoba sufficient certified Cobbler seed (127,000 bus.) to supply the whole province, but until proper grading and storage facilities are provided the Manitoba potato growers will be operating under a severe handicap, and the place which potato growing might play in crop rotation will be small. We have, however, succeeded in introducing into every community in the province the same variety of potatoes and 90 per cent of reports received indicate that the potatoes gave good satisfaction and will be grown again next year.

Boys' and Girls' Clubs—A concerted effort is being made to get the older members of the Boys' and Girls' Clubs to enrol in the registered seed contest, and during the past season grain clubs were organized at Foxwarren, Warren, McCreary, Laurier, Grandview, Durban and Melita. Each competitor sowed from $2\frac{1}{2}$ to 5 acres of registered seed, and fairly good success was met with.

A feature of Extension Work that is meeting with great success is demonstration team work. A demonstration team consists of three girls or three boys—a captain and two assistants. The most suitable age for the members of these teams is 14, 15 or 16 years. A demonstration lasts about forty minutes, during which time one or other member of the team is talking and the other two demonstrating some phase of the subject. The possibilities of this work lie in the fact that the members of the team, in order to secure new and interesting material for their addresses and to answer any questions they may be asked, read everything they can get their hands on.

A team dealing with textiles, for instance, were able for 40 minutes to give interesting information on their subject—information which 75 per cent of their audience did not possess.

The Gladstone flour team were able to trace the grain from their locality, some of it across to Europe, some to the United States and some to the local mills. They were able to compare our production of grain with that of other countries, and they gave the dates of the harvest in other countries and proved that it paid best to sell the grain as soon after harvest as possible.

Another team working on breakfast foods learned that whereas ten years ago Durum wheat was imported into America, today a sufficient quantity is produced to meet the demand of one million pounds a day and have some over to export to Europe.

Thirty subjects are included in next year's demonstrations and among these are grain judging, grain pickling, wheat, oats, rye, sweet clover, macaroni, flour, potatoes, lubricating and fuel oils.

Field Crop Work—This side of agriculture has ever been to the fore with the agricultural representatives, and by newspaper articles, addresses and window displays they have tried to drive home the serious loss due to smut, rust and other plant diseases. Thousands of bushels of seed have been exchanged through the medium of the agricultural representative. Pure seed is being multiplied in several districts, and this will be available for the farmers in the locality in 1923. Two farmers in one district now have 235 bushels of wheat that has been multiplied from one kernel. Growing alfalfa, sweet clover, hemp, millet, Sudan grass, etc., has been undertaken by having the farmers conduct a demonstration plot under field conditions. One district now has a sweet clover association of 30 members testing sweet clover as a fodder, pasture and seed crop for their district.